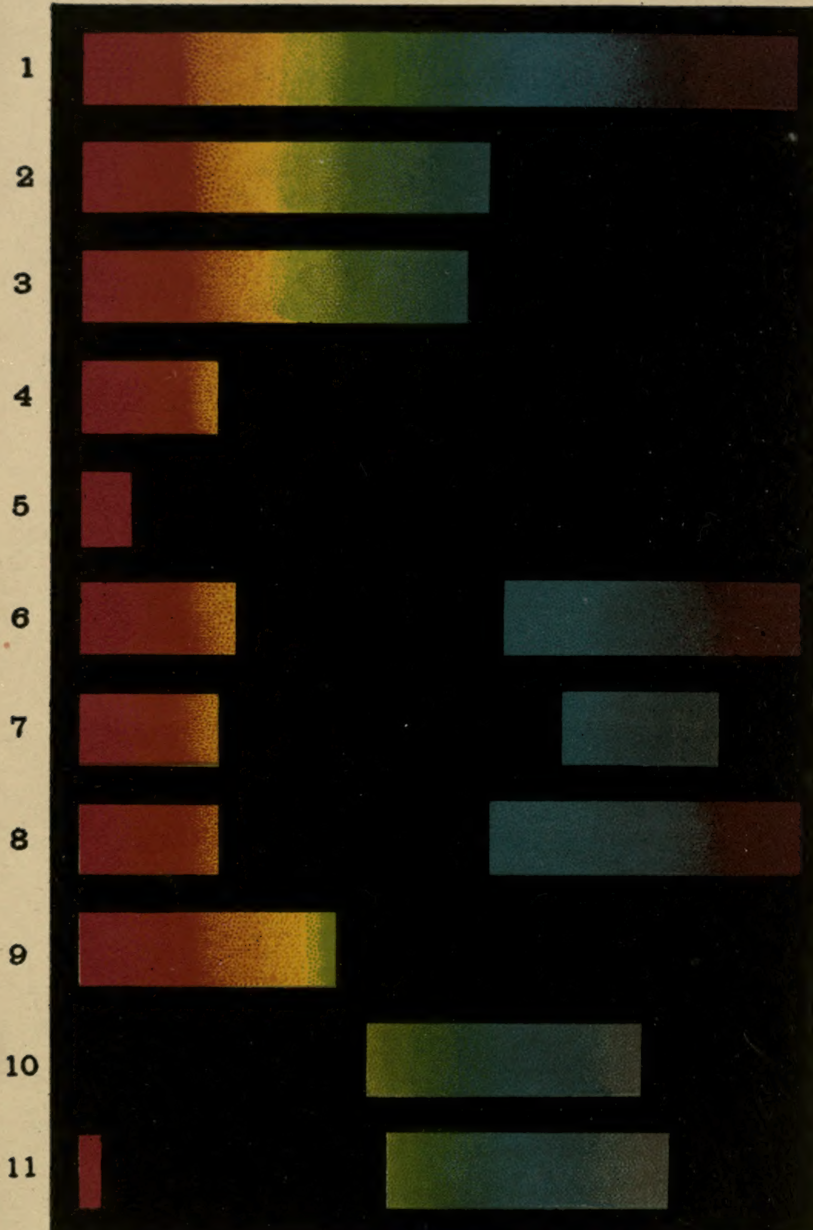
COLOUR

[H]ANDBOOK ON THE THEORY OF COLOUR

GEORGE H. HURST

SECOND REVISED EDITION

PLATE I.



(THEORY OF COLOUR). Absorption Spectra. FRONTISPIECE.

COLOUR

A HANDBOOK OF THE THEORY OF COLOUR

BY
GEORGE H. HURST, F.C.S.

SECOND EDITION, REVISED

BY
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WITH ELEVEN COLOURED PLATES AND SEVENTY-TWO ILLUSTRATIONS AND DIAGRAMS

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PREFACE.

THE subject of colour is one of considerable interest, more especially to artists, painters, dyers, calico printers, and others who use colour or colours in their everyday work. Such persons have considerable practical experience in the mixing and application of colours for various purposes—painting, dyeing and printing of textile fabrics, etc.—but they will no doubt have met with, from time to time, curious effects of mixing the various colours together. To such persons a knowledge of the theory of colour, its cause and production, and a succinct account of the phenomena which occur on mixing colours together in various ways, will be of interest. In the following pages it has been the author's endeavour to present such matters as clearly as possible, and, while keeping in mind the latest investigations in the field of colour, particular attention has been paid to the requirements of the practical man, an explanation being given of the results which are obtained by mixing various dyes and pigments together, phenomena which occur every day to the dyer and painter.

In the compilation of this book the author has received much valuable information on the subject from the manuals of Chevreul, Benson, Rood, Church, and others, and to these he begs to make due acknowledgment.

H. B. STOCKS.

November, 1915.

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COLOUR.

CHAPTER I.

COLOUR AND ITS PRODUCTION.

Light.—Some objects, such as the sun, a gas flame, a candle flame, an electric lamp, etc., emit their own light; these are known as self-luminous bodies, we see them by reason of the light they emit. Other objects, comprising the great majority of those known to us, do not emit light, and therefore are non-luminous. Such objects are rendered visible by reflecting the light which falls upon them from a luminous source. This fact is demonstrated every day when, upon the sun going down, objects become invisible; similarly in tunnels, where absolute darkness reigns, non-luminous objects which pass in lose their visibility.

Colour.—Not only is light necessary for the perception of a non-luminous object but it is also to the light which falls upon them that bodies owe their colour. Go into a flower-garden at mid-day, when the flowers will show many and variegated tints, from the faintest tint on the blush rose to the darkest and most deeply coloured dahlia—pinks, reds, yellows, violets and blues, together with the variegated shades of green of the foliage. Go into the same garden at night: all the colours then will have vanished, the foliage and flowers alike appearing of a neutral tint. Colour, therefore, is the product of light. The same inference may be drawn in the different appearance of a room at night, before and after the light is extinguished.

Dispersion of White Light.—How does light affect the production of colour? The answer is to be found by studying the classical experiments of Sir Isaac Newton. Let the shutters of a window be tightly closed at mid-day, so that no light can enter. Make a hole in the shutter; the light streaming in will pass across the room and appear as a bright spot on the opposite wall. The path of the light will usually be rendered visible as a beam or ray by its reflection from the dust particles which are then noticed to be floating in the air. If now a triangular glass prism is placed in the path of the sunbeam, in such a position that the ray passes through one edge of it, a change both in direction and character of the ray will be noticed; instead of continuing in a straight line, it will be bent out of its course considerably, and will appear, at a greater or less distance laterally from its former position, not as a bright spot of white light, but as a band of variously coloured lights of the same character and position as the colours in the rainbow, which, as a matter of fact, owes its existence to a similar action. This band of coloured light is called the *spectrum*, the colours being known as spectral or *spectrum colours*.

This dispersion of white light by its passage through a prism is illustrated in Fig. 1, which represents the path of white light through one edge of a triangular prism A, the form commonly used in carrying out such experiments, although any other form will give similar results. The lines *aa* represent a ray of white light; if no prism intervened the ray would strike the screen S at *b*; but the ray of light passing into the prism at *c* is refracted in the direction *cd*; and while passing out at *d* it is again refracted, proceeding in the direction *df*; the light is now rendered divergent and therefore forms a band, *ef*, on the screen, S, not of white light, but of various colours, as shown in Plate 1. For convenient reference Sir Isaac Newton divided the spectrum into seven parts

—red, orange, yellow, green, blue, indigo and violet—these being popularly spoken of as the seven colours of the spectrum

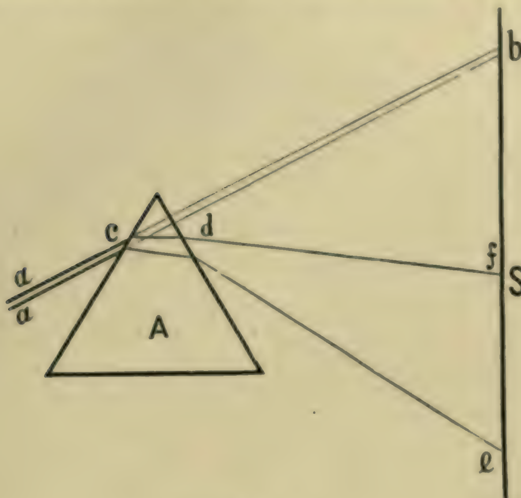


FIG. 1.

or rainbow; but it will be seen hereafter that this division into seven colours is a purely arbitrary one. The spectrum of white light is shown on Plate I, No. 1.

METHODS OF PRODUCING THE SPECTRUM.

There are several methods of producing colour from white light:—

(1) By means of a glass prism;
(2) By means of a diffraction grating;
(3) By means of the polariscope;
(4) By means of phosphorescent and fluorescent bodies;
(5) By means of thin films;
(6) By the action of coloured bodies.

I. BY MEANS OF A GLASS PRISM. Names of Colours.—When, as above stated, a beam of white light is passed through a prism, as shown in Fig. 1, it is dispersed, a band of coloured light or spectrum being produced, Plate I, having at

one extremity red, and at the other violet. Newton, who first discovered this property of the prism, divided the spectrum into seven divisions, *viz.*, red, orange, yellow, green, blue, indigo and violet. In enumerating the colours it is much better, however, to follow the nomenclature of Rood, and designate the principal colours as red, orange-red, orange, orange-yellow, yellow, green, cyan blue, blue and violet. No sharp line of demarcation, however, exists between these colour divisions, the red passing imperceptibly into the orange-red, the orange-red into the orange; this into the yellow, the yellow imperceptibly into the green; this into the blue and the latter into the violet; so that in reality there are not simply seven colours in the spectrum, but an infinite number of colours, for many of which language fails to find sufficient names.

Fixed Lines of the Spectrum.—Fraunhofer was the first to notice that the spectrum of sunlight was not entirely continuous, but was intersected by a number of fine lines; Dr. Wollaston also made the same discovery. These lines, which are called the *fixed lines*, have an interest, since they form standards by means of which the various portions of the spectrum may be located—some of them, being much more prominent than others, are referred to by reference letters, commencing from the red end of the spectrum; these are shown in Fig. 2, which is due to Rood, who gives the following measurements of the various portions of the spectrum, on the assumption that the distance from A to H is divided into 1000 parts.

Fixed Lines of the Solar Spectrum.—The fixed lines of the spectrum shown in the figure fall at the following places:—

A	0	E	363·11
a	40·05	b	389·85
B	74·02	F	493·22
C	112·71	G	753·58
D	220·31	H	1000

Coloured Spaces of the Prismatic Spectrum.—The following table shows the positions occupied by the various colours

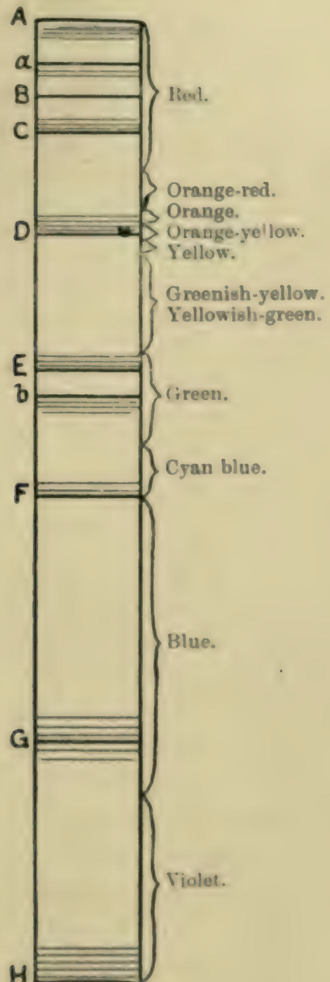


FIG. 2.

as measured by Rood, which correspond closely with observations made by the author:—

	Extends from
Red	0 to 149
Orange-red	149 „ 194
Orange	194 „ 210
Orange-yellow	210 „ 230
Yellow	230 „ 240
Greenish-yellow	240 „ 344
Green	344 „ 447
Cyan blue	447 „ 495
Blue	495 „ 806
Violet	806 „ 1000

Relative Space of the Spectrum Colours.—From these measurements the following table has been constructed, which shows the space occupied by each division or colour :—

Red	149
Orange-red	45
Orange	16
Orange-yellow	20
Yellow	10
Greenish-yellow and yellowish-green	104
Green and blue-green	103
Cyan blue	48
Blue and blue-violet	311
Violet	194

The two foregoing tables, however, do not give the full length of the spectrum, as in front of A there is a dark-red portion which gradually shades off into blackness; while at the other end beyond H there is a faint greyish kind of tint which has been called lavender. It may be added that in making such observations it is necessary that each portion of the spectrum be screened from the rest, a matter which is very easily done, so that the effect of contrast (see Chapter III.) on the hues may be eliminated, and, further, it is desirable that the source of light be as bright as possible.

The order of the colours in the spectrum is that of the wave lengths as shown below. It might be assumed that in a normal spectrum the position of each colour would be in proportion to the wave length, but we find that in the spectrum produced by a glass prism such is not the case; thus in some

portions there is undue crowding, while in others the space occupied by the colours is unduly extended; this is the case with the blue and violet end, notably the latter; while the red, orange and yellow, particularly the orange and yellow, are much shortened.

Wave Motion of Light.—Several theories have been devised to explain all the phenomena of light—that known as the undulatory theory being the one which the majority of physicists have hitherto accepted as most in accordance with the facts. This presupposes that all space, including the bodies in it, are permeated by an exceedingly light or even intangible form of matter known as the ether, and that light is propagated through this medium by means of vibrations or undulations or waves, just as waves in water are propagated and as sound waves in air are formed. In all cases of wave motion there is, practically, no transference of matter, etc., from the source of the movement onwards, but simply an undulation, which is imparted from particle to particle of the medium in which the wave motion is travelling; in this way effects are transmitted to considerable distances from the exciting cause. The sun, or other source of light, generates these vibratory movements in the ether, which ultimately reach the retina of the eye and give rise to the sensation of light.

In waves we recognise two factors—wave length and amplitude. On the surface of a liquid such as water in motion, the distance between the crests of two waves is known as the *wave length*; while the height from crest to trough is known as the *amplitude of the wave*. It has been demonstrated that it is on the magnitude of the latter factor that the intensity, or the power of doing work, of the wave depends; thus of two waves of the same wave length that which exhibits the greatest amplitude being the most powerful, this value varying as the square of the amplitude.

In light, differences of wave length give rise to difference

in colour; thus the waves of red light are longer than those of violet light, while orange, yellow, green and blue light rays are intermediate in their wave lengths.

The Fraunhofer lines, being fixed and therefore constant in position, have been utilised as standards for the measurement of the spectrum. They have been lettered, for ease of reference, from A in the red end of the spectrum to H in the violet end, the wave lengths of the light at these positions in the spectrum have been measured, the measurements being given in the following table in units of $\frac{1}{10000000}$ of a millimetre.

Line.	Position in spectrum.	Wave lengths in ten-millionths of a millimetre.
A	Red	7594
B	Red	6867
C	Red-orange	6562
D	Orange-yellow	5892
E	Green	5269
F	Blue	4861
G	Violet	4307
H	Violet	3968

II. BY MEANS OF A DIFFRACTION GRATING.—The second of the methods referred to above for decomposing white light—that of a diffraction grating—allows of a spectrum of normal length in proportion to the wave lengths of the colours to be obtained. If the glass prism be replaced by a metal or glass plate ruled with a large number of fine lines, in some cases 20,000 to the inch, and the light be reflected from its surface, a spectrum is obtained which contains the various colours almost but not quite in their true position; this diffraction spectrum is, however, much less intense than a prismatic spectrum.

Fixed Lines of the Normal Spectrum.—Measurements made by Rood of a normal spectrum produced in this way give the position of the fixed lines as follows:—

A	0	E	638·92
a	113·74	b	664·79
B	201·61	F	749·24
C	285·05	G	902·07
D	468·38	H	1000

Positions of Colours in Normal Spectrum.—The next table gives the positions of the colours in the normal spectrum according to Rood:—

	Extends from
Red	0 to 330
Orange-red	330 „ 434
Orange	434 „ 459
Orange-yellow	459 „ 485
Yellow	485 „ 498
Greenish-yellow	498 „ 595
Full green	595 „ 682
Blue-green	682 „ 698
Cyan blue	698 „ 823
Violet-blue	823 „ 940
Violet	940 „ 1000

Spaces Occupied by the Colours in a Normal Spectrum.—The amount of space occupied by each colour in such a spectrum is shown in the following table:—

Pure red	330
Orange-red	104
Orange	25
Orange-yellow	26
Yellow	13
Greenish-yellow and yellow-green	97
Full green	87
Blue-green	16
Cyan blue	51
Blue	74
Violet-blue and blue-violet	117
Pure violet	60

If white light can be subdivided into these coloured lights, the question arises whether the spectrum colours themselves may not be further affected by passage through a second prism, as shown in Fig. 3. Here A represents a beam of white light which is caused to pass through a prism P, hence

becoming dispersed, the rays falling on the screen B, an opening in which permits of a portion C passing through and entering a second prism D where it undergoes further dispersion, appearing ultimately on a second screen E at H. The twice dispersed rays, however, are not altered in kind from the rays which enter the second prism, but are simply widened out at H. Therefore each portion of the spectrum consists of only one kind of coloured light rays.

Spectroscope.—An instrument by means of which white light can be resolved into its constituent colours, and by which other observations on colour can be made, is known as the spectroscope. An instrument of this kind is shown in Fig. 5.

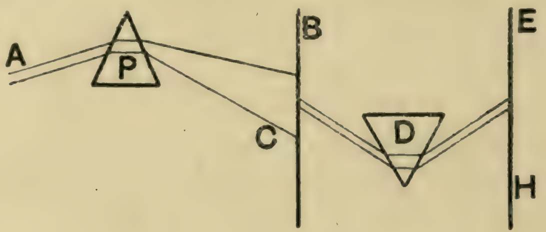


FIG. 3.

In its simplest form it consists of three parts. First, a tube which carries at one end a slit arrangement by means of which a narrow beam of light can be projected into the tube, while at the other end is a lens, called a collimating lens, for the purpose of converting the divergent rays which pass through the slit into parallel rays. Second, a glass prism, through which the rays from the slit are passed; and, third, a telescope by means of which the spectrum thus produced may be observed.

Fig. 4 is an illustration of Browning's direct vision spectroscope, a useful form for taking observations of the absorption spectra of coloured glasses or coloured liquids, it being only needful to hold the glass or a cell containing the liquid

against the end of the apparatus, and direct the instrument to the sky, when the spectrum will be observed.

In many instruments only one prism is used, but if a wider dispersion of the rays is required then more are added, spectroscopes with six prisms having been made. In some instruments there is also an arrangement by means of which a

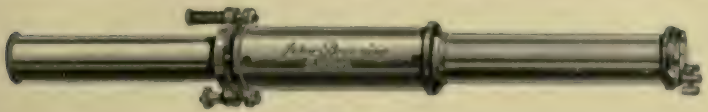


FIG. 4.

graduated scale can be projected into the field of view of the telescope, so that measurements of the spectrum can be made. In some instruments arrangements are made whereby two spectra can be brought side by side for the purpose of comparison.

A diffraction spectroscope is similarly constructed, except

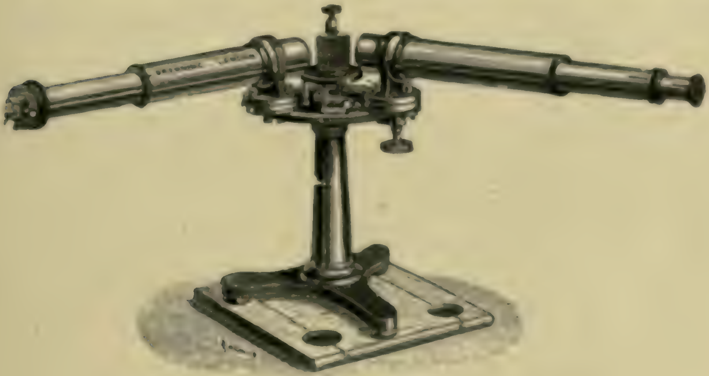


FIG. 5.

that the prism is replaced by a diffraction grating, the light passing through the slit and collimating lens being reflected into the telescope from the grating (see page 6).

Recomposition of White Light.—As white light can be subdivided into many coloured lights, it is possible by recombining these coloured lights together to reproduce white

light; this can be effected in several ways. One method shown in Fig. 6, in which the dispersed beam produced by the prism A is received upon a concave mirror B from which it is reflected to a point D, where the various coloured rays are all converged to again form white light. Instead of using a single

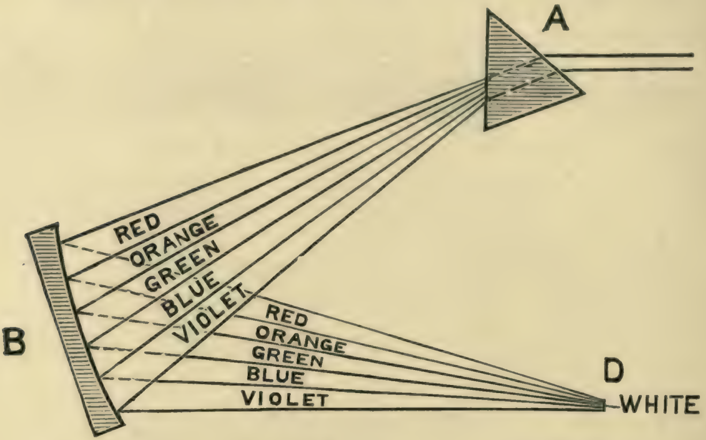


Fig. 6.

concave mirror, the various portions of the spectrum produced by the prism may be received on a series of mirrors each being reflected to one spot where white light will be re-formed.

Another plan, the principle underlying which has been found very useful in the construction of lenses for microscopes

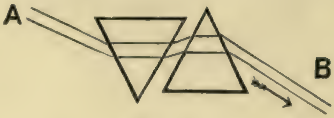


Fig. 7.

and other optical instruments, is to pass the rays from the dispersing prism through a second one placed in the reverse position, as shown in Fig. 7, where the path of the rays of light through the two prisms is traced. It may be pointed out in passing that the degree of dispersion varies with dif-

ferent kinds of glass—a prism made of flint glass, being more dense and refractive, disperses the light much more than a similar prism made of crown glass. The passage of light through lenses is always accompanied by a certain amount of dispersion, which interferes with the definition of objects, surrounding them with a fringe of coloured light, which phenomenon is known as "chromatic aberration". This can be remedied by making the lens a compound one, a convex lens of crown glass being combined with a meniscus or plano-concave lens of flint glass, the latter by its greater dispersive power neutralising the chromatic aberration of the crown glass lens, while the compound lens acts like a simple convex lens to the light rays which pass through it.

Another, but not so perfect a method of combining colours is to paint a white card disc in radial divisions with the seven principal colours of the spectrum, as at 1 in Plate II. If this be made to rotate by means of the mechanism shown in Fig. 44, then, by the operation of persistence of vision, which will be more fully dealt with in another chapter, the various colours appear to blend into one another, and a neutral tint or greyish-white appears. A pure white can never be obtained by this method, by reason of the fact that the pigments used in painting the disc are never pure in colour, a point which will be noticed later.

Hue.—There are three constants, as they are called, which belong to every colour: these are hue, luminosity and purity. The *hue* of a colour is that constant which is commonly denominated by the term colour, as blue, green, red, yellow, rose, or violet, all which terms are employed to distinguish the particular colour sensations one from another. The only true standards for hue are the spectrum colours, and we may measure the hue of any particular colour by noting the position in the spectrum which it occupies or by determining the wave length of the rays coming from it. The following table

gives the position in the normal spectrum, together with the corresponding wave lengths of the light reflected from discs painted with various pigments in imitation of the spectrum colours:—

Name of the colour.	Position in the normal spectrum.	Wave length in ten-millionths of a millimetre.
Vermilion	387	6290
Red lead	422	2061
Chrome yellow	488	5820
Emerald green	648	5234
Prussian blue	740	4899
Cobalt blue	770	4790
Ultramarine (natural)	785	4735
Ultramarine (artificial)	857	4472
Same tinted with Hoffman's Violet BB.	916	4257

Very minute differences in the hue of colours, although distinguishable by the eye, are almost beyond description by any form of notation. Aubert, many years ago, made experiments on the sensitiveness of the eye to changes of colour by means of coloured discs. It was thus found that the addition of one part of white light to 360 parts of coloured light induced a change which was clearly perceptible, changes amounting to only $\frac{1}{100}$ to $\frac{1}{300}$ part of colour being readily perceived. Aubert states that more than a thousand hues are distinguishable in the spectrum, and it is possible to recognise even small variations of these hues. The addition of one part of Chinese blue to 400 parts of barytes is sufficient to impart a very perceptible blue tint to the latter, while the addition of an equal quantity of chrome yellow to such a mixture causes a change in hue, making it become more greenish. Mr. Charles Pierce has also made experiments on this subject, and has found that the perceptive faculty of the eye is the same for all the spectrum colours.

Luminosity.—The second constant of light is *luminosity* or *brightness*. A sheet of yellow paper appears to the eye to be much brighter or more luminous than a sheet of red paper, or

a sheet of blue paper. Given equal illumination, the most luminous surface is a white one; the least luminous, a black one; and between these two there are degrees of luminosity. It is possible to measure the relative luminosity of the spectrum colours by isolating each one and ascertaining relatively the amount of white light which is equal to it in luminosity. Working in this manner the following scale of luminosity has been obtained, the spectrum being divided into 1000 parts between the fixed lines A and H as in the tables which have previously been given :—

LUMINOSITY OF THE SPECTRUM COLOURS.

Colour.	Position in spectrum.	Luminosity.
Dark red	From 40·5 to 57	80
Pure red	„ 104·5 „ 112·7	493
Red	„ 112·7 „ 138	1100
Orange-red	„ 158·5 „ 168·5	2773
Orange and orange-yellow	„ 189 „ 220·3	6985
Orange-yellow	„ 220·3 „ 231·5	7891
Greenish-yellow to green	„ 231·5 „ 363	3033
Blue-green and cyan blue	„ 390 „ 493	1100
Blue	„ 623·5 „ 689·5	493
Ultramarine	„ 493 „ 558·5	90·6
Blue violet	„ 753·5 „ 825·5	36
Violet	„ 896 „ 956	13

The relative luminosity of the spectrum colours is also shown graphically in Fig. 8, where the vertical lines indicate the position of the spectrum colour and the horizontal lines the luminosity. It will be seen that the most luminous portion of the spectrum is the yellow and orange, while the luminosity declines very rapidly on either side to the red or violet. It may be mentioned that the luminosity of the colours as viewed by persons who may be colour blind will differ from the luminosity as seen by a person of normal sight. This subject will be subsequently referred to.

Another method of determining the luminosity of colours is by the employment of the apparatus shown in Fig. 44, which

will be more fully described in Chapter III. A large disc of card coloured with a pigment, the luminosity of the colour of which is to be determined, is placed on the spindle of the revolving apparatus; on this spindle are also fixed two overlapping discs of black and white paper, these being so arranged (see Chapter III.) that the relative proportions of black and white exposed can be varied. When all is ready the combined discs (which have, when at rest, the appearance shown in Fig. 47) are revolved; the black and white then amalgamate and give the sensation of grey, which is more or less luminous according to the proportions of white and black exposed; by varying the proportions a grey is obtained which will appear to have the same intensity as the colour whose luminosity is to be measured. Then, assuming that white light has a luminosity of 100, the luminosity of the colour will be that of the quantity of white exposed in the black and white discs. A small error

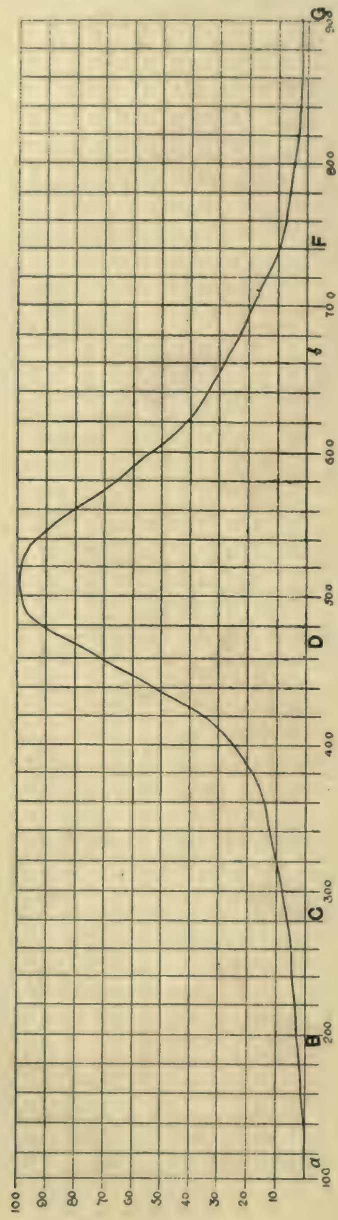
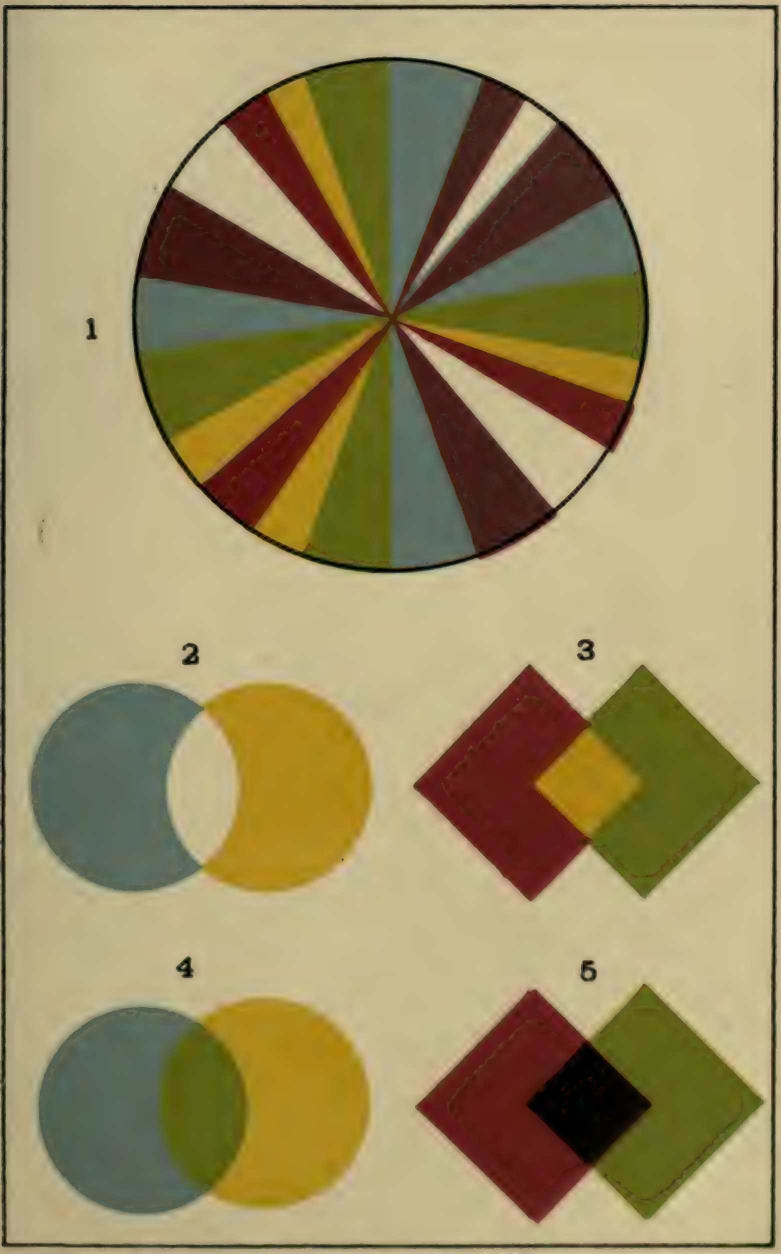


FIG. 8.

PLATE II.



(THEORY OF COLOUR). Effect of Mixing Colours. *To face p.* 16.

is introduced if the assumption is made that the black disc has no luminosity, since it has a small luminosity, usually about 4 to 5 per cent. of that of a white disc. The author has obtained the following results by this method :—

White paper	100
Vermilion	20·5
Orange-red	40·3
Ochre	55·5
Chrome-yellow	61·1
Emerald green	51·4
Green	50
Ultramarine	50
Blue	20·5
Umber	22·2

These measurements are not easy to make, but by taking the mean of several sets of observations a fair approximation to the truth may be obtained.

Compared together it is possible for two colours, a red and a blue for example, to appear of the same degree of luminosity.

Extent of surface has some effect in influencing impressions of luminosity. A large surface of colour of low luminosity will appear to overpower a small surface of colour of high intensity, the two colours appearing to have the same luminosity. Artists are well aware of this fact, and often take advantage of it in painting, introducing a spot or patch of a highly luminous colour into a mass of dark, sombre colouring with very good effect.

The judgment of equal luminosity of different colours is, perhaps, a psychological one, two observers may not regard the same pair of colours as equally luminous, just as in different persons the perception of shade and tint in colours varies so that in matching colour tints no two people will arrive at precisely the same results.

Purity.—The third constant of colour is *purity*. By purity of colour is meant the absence from a colour of any

admixture of another colour or of white light. The standard of purity in all cases is the spectrum, the spectral colours being absolutely pure; they are, therefore, the standard for comparison with the light which comes from coloured objects, painted surfaces, etc. When the comparison is made it will be noticed that while such surfaces or coloured bodies may correspond in hue with some portion of the spectrum, yet the coloured surface appears pale in comparison with the spectrum colour; this is due to the colour which is being compared being diluted with more or less white light. If, however, we make a mixture of the spectral colour with

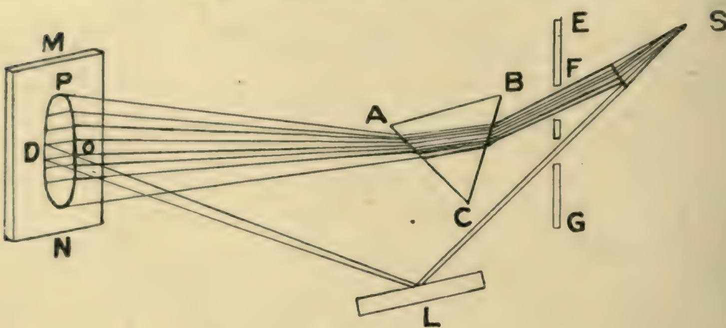


FIG. 9.

white light it will be possible to reduce the intensity of the spectral colour to that of the coloured surface; then if the amount of white light added be measured, it necessarily gives the amount of white light admixed with the colour in question. Fig. 9 shows one method of mixing white light with the spectral colours.

In this drawing ABC represents a glass prism, S is a beam of white light passing through a hole, F, in a shutter, EG; this light, after passing through the prism, forms a spectrum, P, on a screen, MN; another beam of white light from S passing through another hole in the shutter, EF, falls upon a mirror, L, and is reflected thence to the

screen at O; by tilting the mirror, L, the white light may be thrown upon any part of the spectrum, P, and its effect upon the different colours observed.

Thus, for instance, vermilion, or rather the light reflected from a surface painted with this pigment, can be matched by mixing the light from a portion of the red end of the spectrum with 20 per cent. of white light. In a similar way it has been ascertained that emerald green reflects nearly the same amount of white light, and ultramarine about 25 per cent. The effect of white light when mixed with the coloured light is to reduce its intensity, and thus soften it, causing it to have less action on the eye; when the proportion of white light is considerable the influence of the coloured light is reduced to such an extent that it becomes almost invisible, and we then get what are termed *grey tints* varying in tone—reddish, greenish, bluish, etc.—according to the colour from which they are produced. This question will be discussed in detail in another chapter.

III. PRODUCTION OF COLOUR BY THE POLARISCOPE.—When a ray of white light is passed through a prism of Iceland spar, *i.e.* a transparent crystal of calc spar, it undergoes what is known as *double refraction*, that is one portion of the ray is refracted more than the other, so that we get two

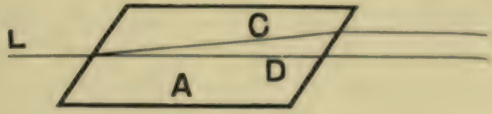


FIG. 10.

rays which pass out of the prism parallel to one another (see Fig. 10). These two rays possess properties different from the original ray of white light; they have become what is rather inaptly termed *polarised*. If the prism of Iceland spar be cut in two diagonally and the two surfaces cemented

together, then it is found that while one ray passes through the division unchanged, the other ray is reflected from the cemented surface and passes out at the side of the prism. A prism thus cut and arranged, known as a *Nicol's prism*, forms a very convenient means of obtaining polarised light for experimental purposes; its effect on a ray of light is shown in Fig. 11.

The Nicol's prism is shown with the diagonal cut AB, the two halves being cemented together with Canada balsam. A beam of light, C, entering the prism at D, becomes doubly refracted during its passage through the prism; on reaching the cemented surface AB, one of the two beams is reflected to the side of the prism, as shown in the drawing, while the other passes through the prism unaltered.

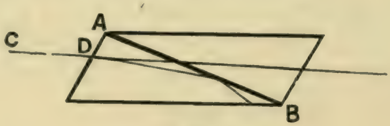


FIG. 11.

Another manner of obtaining polarised light is by reflection from a bundle of glass plates (see Fig. 13). It has been found that, when a plate of glass is placed at an angle of 33° to the incident ray, the light which is reflected is very largely polarised; by employing a bundle of glass plates the effect is increased and a sufficient quantity of polarised light obtained to perform a large number of experiments. If the light from such a bundle of plates is caused to pass into a Nicol's prism it is found on rotating the latter that in one position of the prism the light passes through unchanged, while at a right angle, *i.e.* 90°, to this no light whatever emerges. The same effect can be produced if a second bundle of glass plates is employed; if this second bundle is arranged with their faces towards the polarising bundle then the light is reflected; on the other hand, if they have their edges towards

the polarising bundle the light is not reflected but passes through the second bundle of plates. If a piece of selenite be interposed between the two bundles of glass plates its reflection on the second bundle will be more or less coloured, and on rotating the second bundle of plates it will be found that the colour changes according to the position of the bundle. If instead of the selenite a piece of rock crystal cut perpendicular to the axis of the crystal be interposed, colour will also be produced, this colour also changing as the second bundle of plates is rotated.

The instrument employed to produce polarised light is

FIG. 12.

known as the *polariscope*. A simple form of this instrument is shown in Fig. 12; while Fig. 13 is a diagrammatic representation of it. A bundle of glass plates, A, rests on the bottom of the box, this represents the polariser; light at the requisite angle is allowed to fall on this bundle of glass plates, and being reflected upwards is received in the *analyser*, B, which may either be a Nicol's prism, as in the instrument illustrated, or a bundle of glass plates. The objects, if large, are placed on the support D; or, if small, are held in a support E, while at F is a lens for focussing the light on the objects when these are placed at E, or when these are placed at D, on the

analyser B. C is a ground glass plate which diffuses the light falling on the plates A. Polariscopes are now fitted to most microscopes, both polariser and analyser containing a Nicol's

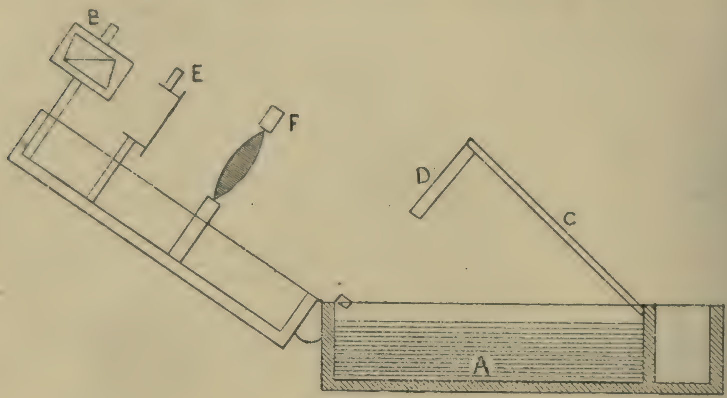


FIG. 13.

prism, the former being placed under the stage of the microscope, while the latter is fitted directly above the objective or over the eye-piece.

Another form of the polariscope is shown in Fig 14. In

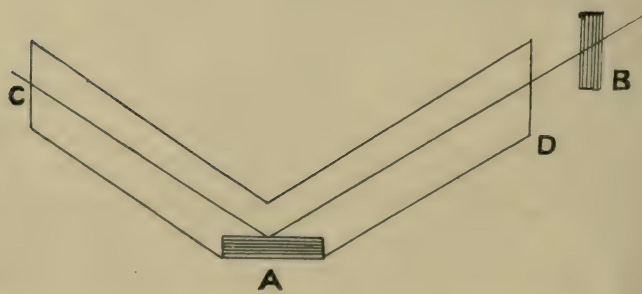


FIG. 14.

this drawing, A is a bundle of glass plates, the polariser, while the enclosing tubes CD are so arranged that the light strikes the plates at the proper angle (see above); B is a similar bundle of glass plates, the analyser, in which the

effects produced by the passage of the polarised light from A can be observed. This drawing shows a form of polariscope suitable to be used either as a table polariscope for individual observation or as a polariscope in conjunction with the optical lantern for demonstrations to a number of persons.

Many substances, when placed between the polariser and analyser, give rise to the production of chromatic effects; thin plates of selenite, in particular, being useful for this purpose. The colour produced is dependent upon the thickness of the plate—thus one particular thickness will give rise to a yellow colour, another to a red, another to a green—if the plate of selenite is of uneven thickness then quite a play of colours will be produced. On rotating the analyser the colours change, and when the analyser has been rotated through a quarter of a revolution the colour produced is complementary (see Chapter III.) to that originally obtained. If a quartz plate be used, then, as the analyser is rotated, the colours follow each other in the order of the spectrum—changing from red to orange, orange to yellow, yellow to green, and so on. Some quartz crystals require the analyser to be rotated to the right in order to obtain the colours in this order—such are known as right-handed (dextro-rotatory) crystals; others require the analyser to be rotated to the left—such being known as left-handed (lævo-rotatory) crystals. Some solid bodies, although not producing any chromatic effect, have an action on the ray of polarised light. It has been stated above that when the analyser is at right angles to the polariser no light is transmitted; if now a substance of this class be introduced between the polariser and the analyser, light will again be transmitted, but without colour—this shows that the interposed substance has some action on the ray which passes through it. On rotating the analyser through a small angle the light is again obliterated, showing that the substance has a rotatory action on the ray of polarised

light: some require the analyser to be rotated to the right, these are called dextro-rotatory bodies; while others require it to be rotated to the left, these are called lævo-rotatory bodies; this action is strictly quantitative and by means of it many substances, as sugar, turpentine, etc., can be estimated, this property is, therefore, of value from an analytical point of view and is often taken advantage of. This feature of the subject is, however, beyond the scope of the present work.

When the ray of polarised light is caused to pass along the optic axis of certain crystals—potassium nitrate, tartaric acid, borax, calcite, sugar, ferrocyanide of potassium, phosphate of potassium, etc.—the analyser exhibits a very fine effect; this consists of a series of concentric coloured circles round the axis of the crystal, and lying upon these is a black cross; on rotating the analyser, the black cross gives place to a white one, while the concentric rings change colour and assume the complementary hues; the brilliance of the colours being great. The character of these phenomena vary with different substances: in some cases the rings are sharply defined; in others, they pass insensibly into one another; in some the black cross is prominent, while in others it is but faint. Some crystals are biaxial, and, therefore, two sets of coloured rings and two black crosses, more or less intersecting one another, are obtained.

When masses of crystals which act on polarised light are allowed to form in thin layers on a piece of glass, these crystals, viewed in the polariscope, give rise to such beautiful colour effects that they almost defy description; once seen, however, they are not readily forgotten, on account of the harmony of colouring which prevails; the immense variety of form and of colour which is presented by different substances is nevertheless marvellous.

Glass which has been heated and then suddenly cooled, or has been subjected to a strain, also produces colour effects;

in this case the concentric coloured rings and black cross sometimes appear; at others, various effects, according to the conditions.

Starch grains when viewed under a microscope fitted with a polariscope show black crosses in a similar way to crystals, in some cases the appearance is characteristic and suffices to distinguish a particular starch from others.

It is quite beyond the scope of this book to enter into a full account of the phenomena of polarised light or attempt an explanation of how and why these effects are produced; the reader is referred to books dealing specially with this subject for such information. There is, however, just one other point that may be touched upon, seeing that it has a bearing upon the production of colour.

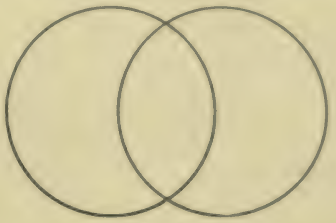


FIG. 15.

If, instead of using a Nicol's prism as an analyser, a simple prism of calcite be substituted, the light from the polariser being allowed to fall on this prism through a small diaphragm, then, on looking through the eye-piece of the instrument, two white discs will be observed overlapping (as shown in Fig. 15). If, now, between the polariser and the calcite prism be placed a thin plate of selenite, the discs will appear coloured, the colours varying with the thickness of the film of selenite; the chief feature, however, about them is that the two discs appear of different colours, these being complementary to one another—thus, while one may be green the other will be red, one yellow and the other blue, and so on. Where, however, the discs overlap one another this portion is usually white, showing that by the union of two complementary colours white light may be formed, see Plate III., No. 5 *et seq.* This has a very important bearing on the

theory of colour, which will be developed in a subsequent chapter.

IV. COLOUR PRODUCED BY PHOSPHORESCENCE AND FLUORESCENCE.—Certain compounds, notably the sulphides of barium, strontium and calcium, in the state of a fine powder when exposed to bright light, and then taken into a dark room, are found to glow with light, differing in hue or tint in each case; such glow is known as *phosphorescent light.* The nature or cause of this phenomenon is not thoroughly understood, but research has shown that a large number of bodies are capable of exhibiting phosphorescence when first exposed to a bright light, as from burning magnesium, and then viewed in a dark place. Some substances exhibit this phenomenon more strongly under a vacuum than they do under ordinary conditions. The production of the so-called "luminous paint," which shines in the dark after exposure to light, is based on this property of barium and strontium sulphides being used.

When a solution of eösine in alcohol is viewed by transmitted light it appears of a pale crimson colour, yet when looked at direct it exhibits a beautiful yellow glow, which is known as *fluorescence.* Many substances are found to have this property, and are termed *dichroic.* Glass tinted or coloured with uranium has this property; when looked through it shows a pale yellow tint, yet it reflects a bluish-green light. Uranium glass has another property: if placed in a dark room and illuminated with violet light it does not reflect violet light, but appears to glow or to be self-luminous, the light having a bluish-green tint; this change of hue is very remarkable, because it would appear as though the uranium glass had the property of changing the wave length of the light which falls upon it. A change in colour can only be accounted for by a change in the wave length of the emitted

light. Stokes has made numerous experiments on uranium glass and substances which act on light in a similar manner; he finds that in each case the wave length is affected and, further, that the alteration consists in an increase. The property of fluorescence is possessed by many substances, *e.g.*, platino-cyanide of barium, thallene, etc., etc.

V. PRODUCTION OF COLOUR BY INTERFERENCE.—When an oily substance is dropped upon the surface of water it spreads over the latter in the form of a very thin layer, giving rise to the production of a play of beautiful colours which, chameleon-like, rapidly changes in hue and extent. These colours are produced in a peculiar manner; the waves of light impinging upon the film of oil undergo both refraction and reflection, the film, however, is so thin that the waves of light reflected from its upper and lower surfaces clash with one another, whereby some are quenched, the remainder passing forward to the eye of the observer as coloured light; the degree of quenching depends upon the thickness of the film, and as this is constantly changing, the colours likewise vary. Interference colours are also produced when light is reflected from regularly marked surfaces where the markings are very minute.

Interference colours are frequently met with in nature: the exquisite colouring found on many beetles' wings, the iridescent hues seen in many shells, the pearly tints of fish scales, the colours on many birds' feathers are due to this cause. The colours on a soap bubble, the hues of many minerals, and the iridescence of many varieties of glass are due to interference.

For the purpose of showing the colours of thin films the apparatus illustrated in Fig. 16 may be used. This consists of a plano-convex lens, CD, and a double-convex lens, AB, both of long focal length, and three pairs of screws, PP, for the

purpose of screwing them together and producing a regular pressure at the point where the two lenses touch each other. By pressing the lenses together there appears a black spot in the centre with a series of coloured rings or spectra concen-

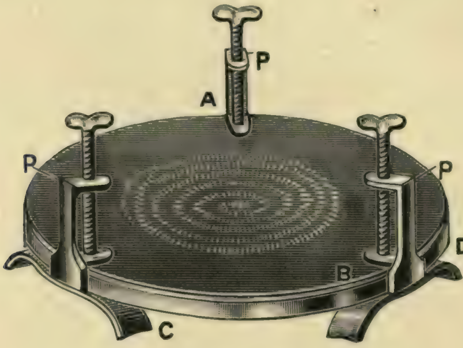


FIG. 16.

tred round it as shown in Fig. 17, which represents about one-half of the system ; the farther each ring may be from the centre the fewer are the colours in it. This is the effect as seen by reflected light. If the rings be viewed by transmitted light,

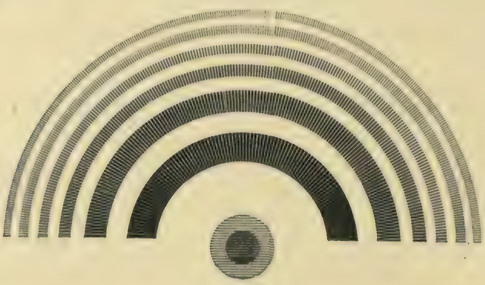


FIG. 17.

then the central spot appears to be white, and the system of rings are seen in colours which are complementary to those observed by reflected light. Fig. 18 shows the order of the tints passing from the centre outwards as seen by reflected

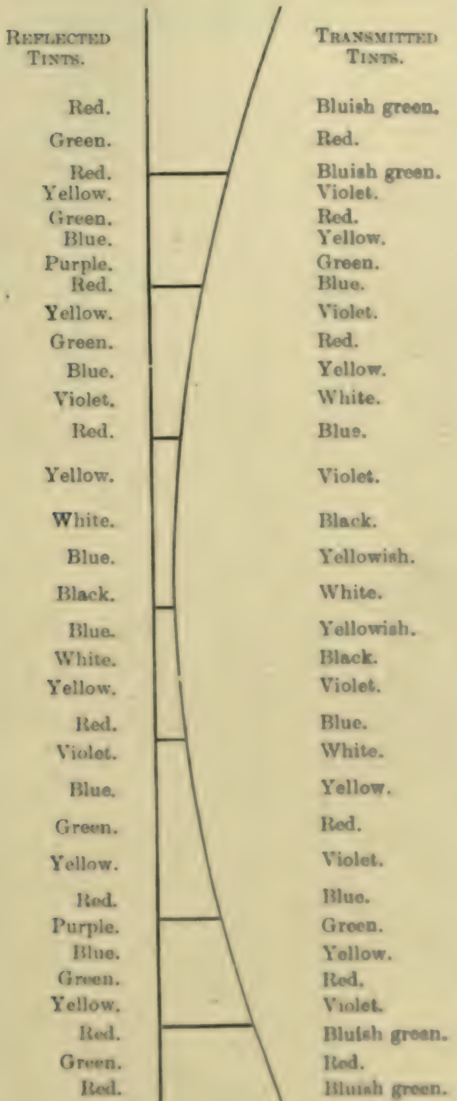

Reflected Tints.
Transmitted Tints.
Red.
Bluish green.
Green.
Red.
Red.
Bluish green.
Yellow.
Violet.
Green.
Red.
Blue.
Yellow.
Purple.
Green.
Red.
Blue.
Yellow.
Violet.
Green.
Red.
Blue.
Yellow.
Violet.
White.
Red.
Blue.
Yellow.
Violet.
White.
Black.
Blue.
Yellowish.
Black.
White.
Blue.
Yellowish.
White.
Black.
Yellow.
Violet.
Red.
Blue.
Violet.
White.
Blue.
Yellow.
Green.
Red.
Yellow.
Violet.
Red.
Blue.
Purple.
Green.
Blue.
Yellow.
Green.
Red.
Yellow.
Violet.
Red.
Bluish green.
Green.
Red.
Red.
Bluish green.

Fig. 18.

SIR ISAAC NEWTON'S TABLE OF THE COLOURS OF THIN PLATES OF AIR, WATER AND GLASS.

Succession of Spectra, or Orders of Colours.	Colours produced at the thicknesses stated in the last three columns.		Thickness in millionths of an inch.		
	Reflected.	Transmitted.	Air.	Water.	Glass.
First Spectrum, or order of colours.	Very black.		$\frac{1}{2}$	$\frac{3}{8}$	$\frac{10}{31}$
	Black.	White.	1	$\frac{3}{4}$	$\frac{20}{31}$
	Beginning of black.		2	$1\frac{1}{2}$	$1\frac{2}{7}$
	Blue.	Yellowish-red.	$2\frac{2}{5}$	$1\frac{4}{5}$	$1\frac{11}{20}$
	White.	Black.	$5\frac{1}{4}$	$3\frac{7}{8}$	$3\frac{2}{5}$
	Yellow.	Violet.	$7\frac{1}{9}$	$5\frac{1}{3}$	$4\frac{3}{5}$
	Orange.		8	6	$4\frac{1}{6}$
	Red.	Blue.	9	$6\frac{3}{4}$	$5\frac{4}{5}$
Second Spectrum, or order of colours.	Violet.	White.	$11\frac{1}{6}$	$3\frac{3}{8}$	$7\frac{1}{5}$
	Indigo.		$12\frac{5}{6}$	$9\frac{5}{8}$	$8\frac{3}{4}$
	Blue.	Yellow.	14	$10\frac{1}{2}$	9
	Green.	Red.	$15\frac{1}{8}$	$11\frac{1}{3}$	$9\frac{5}{7}$
	Yellow.	Violet.	$16\frac{2}{7}$	$12\frac{1}{5}$	$10\frac{2}{5}$
	Orange.		$17\frac{2}{9}$	13	$11\frac{1}{6}$
	Bright red.	Blue.	$18\frac{1}{3}$	$13\frac{3}{4}$	$11\frac{5}{6}$
	Scarlet.		$19\frac{2}{3}$	$14\frac{3}{4}$	$12\frac{2}{3}$
Third Spectrum, or order of colours.	Purple.	Green.	21	$15\frac{3}{4}$	$13\frac{11}{20}$
	Indigo.		$22\frac{1}{10}$	$17\frac{4}{7}$	$14\frac{1}{4}$
	Blue.	Yellow.	$23\frac{2}{5}$	$17\frac{11}{20}$	$15\frac{1}{10}$
	Green.	Red.	$25\frac{1}{5}$	$18\frac{6}{10}$	$16\frac{1}{4}$
	Yellow.		$27\frac{1}{7}$	$20\frac{1}{3}$	$17\frac{1}{2}$
	Red.	Bluish-green.	29	$21\frac{3}{4}$	$18\frac{5}{7}$
	Bluish-red.		32	24	$20\frac{2}{3}$
Fourth Spectrum, or order of colours.	Bluish-green.		24	$25\frac{1}{2}$	22
	Green.	Red.	$35\frac{2}{7}$	$26\frac{1}{2}$	$22\frac{3}{4}$
	Yellowish-green.		36	27	$23\frac{2}{9}$
	Red.	Bluish-green.	$40\frac{1}{2}$	$30\frac{1}{4}$	26
Fifth Spectrum.	Greenish-blue.	Red.	46	$34\frac{1}{2}$	$39\frac{2}{3}$
	Red.		$52\frac{1}{2}$	$39\frac{3}{8}$	34
Sixth Spectrum.	Greenish-blue.		$58\frac{3}{4}$	44	38
	Red.		65	$48\frac{3}{4}$	42
Seventh Spectrum.	Greenish-blue.		71	$53\frac{1}{4}$	$45\frac{4}{5}$
	Reddish-white.		71	$57\frac{3}{4}$	$49\frac{2}{3}$

and by transmitted light. It may be stated that a layer of air ceases to reflect light when the thickness is less than half a millionth of an inch; that with a thickness of more than seventy-two millionths of an inch it reflects white light, and that between these two limits it reflects colours in various degrees. In the same way water of a thickness of three-eighths of a millionth of an inch ceases to reflect light; above fifty-eight millionths of an inch it reflects white light, and other colours at intermediate thicknesses. Glass of a thickness of one-third of a millionth of an inch does not reflect light; at a thickness of fifty millionths of an inch it will reflect white light. Sir Isaac Newton, who investigated the colours of thin films, has given the table, on opposite page, of the various spectra which can be observed, together with the varying thicknesses of air, water and glass at which they are obtained.

The production of colour when white light falls on coloured bodies, the sixth of the ways enumerated at the head of this chapter, is of sufficient importance to merit discussion in a separate chapter.

CHAPTER II.

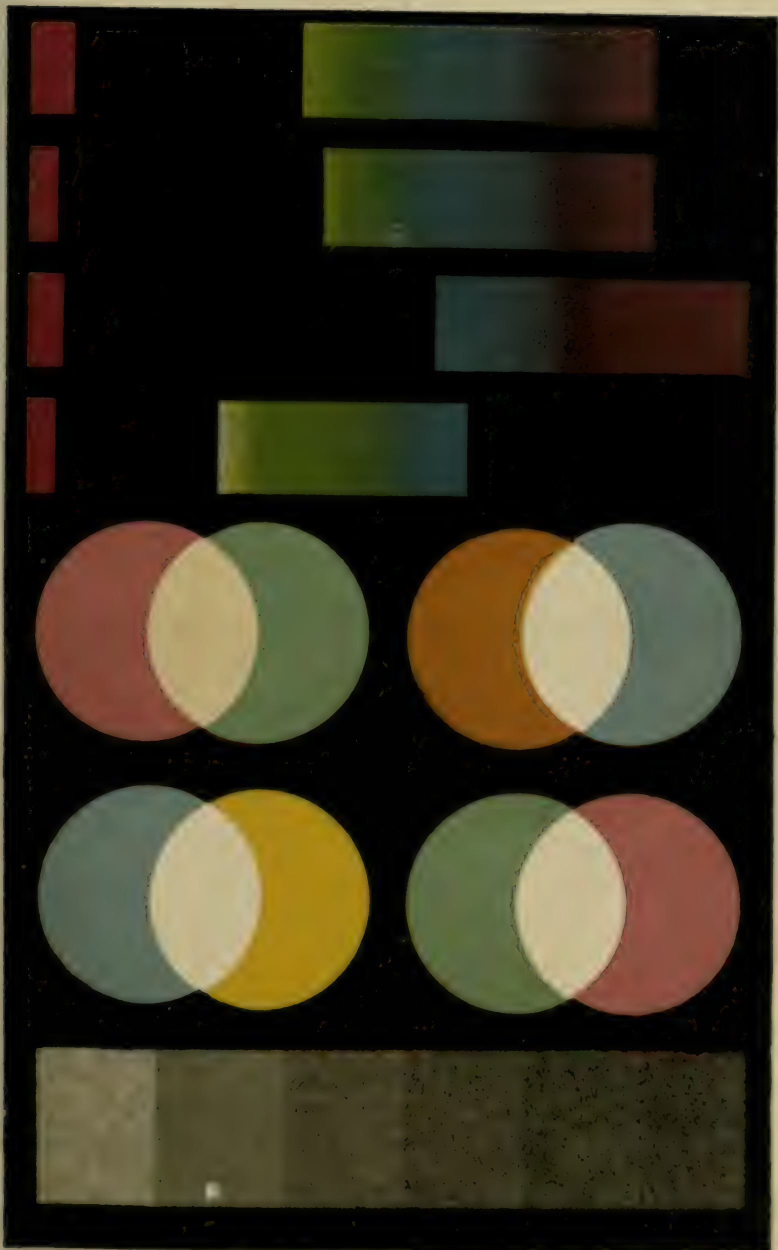
CAUSE OF COLOUR IN COLOURED BODIES.

VI. **PRODUCTION OF COLOUR BY THE ACTION OF COLOURED BODIES.**—We have now to discuss, as far as may be possible, the reasons why any particular substance presents itself to our eyes as coloured. The final answer to this question cannot really be given, as we are still unable to state definitely why one substance should have a red colour, another one blue, and still another one green. For a complete answer we shall have to learn more of the intramolecular structure of bodies than we know at present in order to ascertain why they are able to select some of the rays of light and absorb them, while other rays are not affected; possibly we may find that the molecules of these bodies are in such a state of motion as to enable them to submerge light rays of certain wave lengths while others remain unchanged.

We see coloured bodies under two conditions: in the first the material being transparent the light comes to our eyes through the substance, or is transmitted, as is the case with stained glass, coloured solutions and liquids, etc.; while in the second case, more particularly with opaque bodies, the light is reflected from the object to our eyes. We will first consider colours produced by transmission and subsequently the colours due to reflection.

Transmitted Colours.—When white light passes through coloured glass, and from thence to the eye of the observer appearing as coloured light, then, to produce such light, it is

PLATE III.



(THEORY OF COLOUR). Absorption Spectra and Effect of Mixing Coloured Lights.
To face p. 32.

evident that the glass must have had some action on the light; probably it has absorbed some of the rays which go to make up the white light that fell upon it and permitted others to pass through, the nature and degree of absorption depending upon the composition of the glass and the character of what we call the colouring matter present therein.

To understand fully the nature of the absorption of light by coloured bodies we must observe the spectrum of the rays which are transmitted, and compare these with the spectrum of white light. This is a comparatively simple matter: if the object to be examined is coloured glass then it suffices to hold it in front of the slit of an ordinary spectroscope; or, in the case of a coloured solution or liquid, to hold a glass vessel containing it in front of the slit. With regard to dyes from coal tar their absorption-spectra can very conveniently be obtained by a plan described by Mr. Arthur Dufton: an ordinary photographic dry plate is taken, and the silver salts removed by placing the plate in a bath of hyposulphite of soda and thoroughly washing afterwards; the plate is next immersed in a weak solution of the dye stuff. In the case of the basic and direct dyes such as Magenta, Safranine, Chrysoidine, Chrysamine, Benzo blue, etc., no addition need be made to the solution; but with acid and azo colours, such as Acid green, Naphthol yellow, Orange, Eosine, etc., a few drops of acetic acid may be added. Any depth of colour may be obtained on the plates within limits by regulating the duration of immersion in the dye solution; in time, however, the gelatine film on the plate becomes saturated with the colour, and no further increase in intensity is obtainable. The gelatine plate so obtained may be placed in front of the slit of the spectroscope and the spectrum of the colour obtained. The author has made numerous plates in this way, finding it an easy and efficient mode of working.

When we examine by means of the spectroscope the light

transmitted by red glass, we find that the spectrum which is obtained is not a complete one compared with the spectrum of white light; only the red and a part of the orange portions of the spectrum are visible—the remainder of the colours of white light have been absorbed in its passage through the glass. This is shown in Fig. 19, where the spectra of white light and red glass are compared. It will be seen that the red glass permits only the red, orange, and part of the yellow to pass, while the rest of the yellow, all the green, blue and violet rays are suppressed or absorbed. In connection with the colours due to fluorescence we have seen that

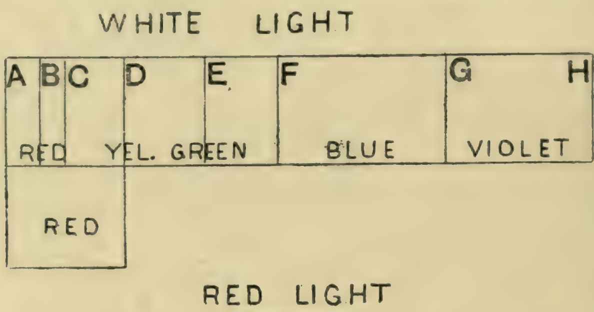


FIG. 19.

the phenomenon is brought about by the fluorescent body acting on the light which falls upon it and changing its wave length; hence the question may arise, May not a red substance act upon the light which falls upon it in such a manner as to change it into red light? That this is not the case may be shown in several ways, as will be demonstrated in the following chapters; but one simple way may be given here. If the spectrum of white light be thrown on a wall or screen and observed through a piece of red glass, we shall see the red portion of the spectrum, the rest being apparently eliminated; if a piece of green glass be substituted for the red, then we shall see the green portion only, the red, yellow, blue and violet being absorbed or their transmission prevented; in the

same way a piece of blue glass will only permit the passage of the blue and violet rays. It might be inferred that if the coloured glass exercises a degree of selection on the light which is presented to it, and will only allow certain rays to pass through, then, if red glass will stop all but the red rays and green glass all but the green rays, a combination of both should stop all rays from passing; this is actually the case—a piece of green and a piece of red glass when superposed one on the other will stop all light from passing through them, and on looking at them will appear black in consequence.

We have in the foregoing remarks assumed that a red glass only transmits red rays; in reality it does more than this. If we take a spectroscope and fix across one half of the slit a piece of red glass we shall see, first, an ordinary luminous spectrum, and, secondly, the spectrum of the red glass; by this means we shall be able to compare the two together and better observe the effect of transmitting the light through the red glass. In the first place we shall see that the glass not only prevents the transmission of some of the colours, but also that the intensity of those which are transmitted is very considerably reduced. The reduction in intensity can be measured, but it is difficult to show the relative intensity by shading on paper. One way of doing this is shown in Fig. 20, which represents the spectrum of red glass. Here the whole rectangle indicates the extent and intensity of the light of a complete spectrum. The rectangle AHNO shows the space occupied by the spectrum of white light, while the shaded portion gives some idea of the extent and intensity of the light transmitted by the red glass; the height NL of this portion shows the relative intensity of the light transmitted compared with the light of the corresponding portion of the spectrum of white light. We see from this that while red glass permits the transmission of some of the red rays, it also allows a portion of the orange and, in a greatly diminished

degree, the yellow rays, together with even a smaller proportion of the green and blue rays, to be transmitted; but the violet rays are completely cut off. The degree of luminosity of the rays from greenish-yellow to blue which the glass transmits being so small, it is to the eye overpowered by the preponderance

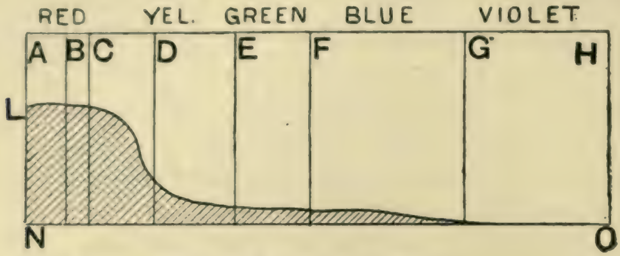


FIG. 20.—Spectrum of red glass.

of red rays; consequently the light from the glass appears red; it is only when we view the red light through the spectroscope that we find that it contains yellow, green and blue light to a small extent. It must, however, be pointed out (as will be seen more fully later) that the character and extent

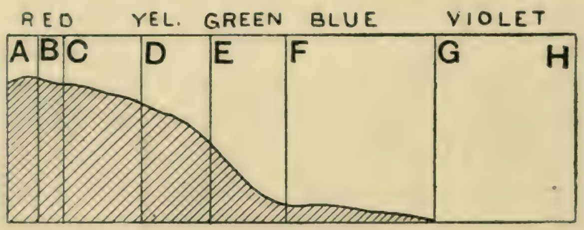


FIG. 21.—Spectrum of orange yellow glass.

of the rays which can be transmitted vary with different kinds of red glass; some may cut off more of the green and blue rays than others; and some may transmit more of the orange and yellow rays. Compare Plate I., in which are given the spectra of various red bodies.

As another example we may take a glass of an orange-yellow colour, the spectrum of which is shown in Fig. 21.

Here we see that the glass transmits the red, orange and yellow rays with a slightly diminished intensity; the green with a considerable diminution of intensity, a little of the blue and a very small portion of the violet; the eye sees, as it

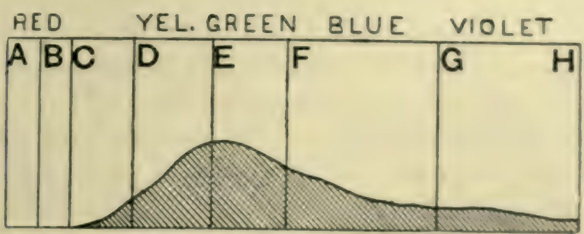


FIG. 22.—Spectrum of green glass.

were, the mean of these colours, therefore we say the glass is orange-yellow. Fig. 22 shows the absorption spectrum of a piece of green glass. In this case the glass materially reduces the intensity of the light; this is shown by the curve barely extending to half the height of the normal spectrum in the green portion, while it tapers off towards the yellow on one

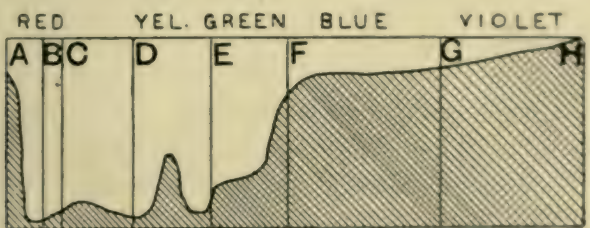


FIG. 23.—Spectrum of blue glass.

side and violet on the other. It will be noticed that the glass permits the violet rays (but with diminished intensity) up to the H line to pass, while it stops all the red.

In Fig. 23 is shown the spectrum of a blue glass. This is much more complex in character than any of the others. Every part of the normal spectrum is represented, the green-

blue to violet being in considerable amount; while a portion of the spectrum close to the A line in the red is shown, there is but little of the orange-red near the B line, a little more of the orange in the neighbourhood of the C line, a little of the yellow and somewhat more of the greenish-yellow in the space between the D and E lines.

The quantity and character of the light which is absorbed by coloured glasses, or coloured media of any kind, depend upon the thickness or depth of colouring; thus red colouring matter, when in a thin layer, may permit some of the green and even small quantities of the blue and violet rays to pass, in a thicker layer, with red, perhaps, some of the green rays may emerge; while in a very thick layer none but red rays may pass. This explains how it is that the dyer, by using more or less dye-stuff, is able to produce so many varieties of tint, varying somewhat in hue, from the same colouring matter; when, for instance, only a small amount of dye-stuff is applied it is not in sufficient quantity to neutralise, so to speak, all the white light which is reflected from the fibre on which the dye-stuff is applied; as the quantity of dye is increased less white light is reflected, the colouring matter then shows its normal hue.

Absorption Spectra of Colouring Matters.—In the practical applications of dyes for the colouring of textile fabrics of all kinds we are accustomed to mix them together in a variety of ways to produce particular shades that may be desired; thus, for instance, a green is dyed on wool by using picric acid or Tartrazine with indigo extract; the first named is a yellow dye-stuff, the last a blue dye-stuff. Browns are dyed by uniting archil (a red dye) with indigo (a blue dye) and acid yellow (a yellow dye) in suitable proportions. To understand how these various combinations, and others of a similar character, can bring about the desired colour we must know their colour absorptive action on white light.

This is done by observing their absorption spectra. On Plates I. and III. and in Figs. 24 to 29 are given the absorption spectra of several of the most useful colouring matters and dyes.

In Plate I., No. 2, we have the spectrum of Picric Acid. This shows all the red, yellow and green, and a portion of the greenish-blue, but the rest of the spectrum is extinguished. We see now that picric acid is capable of dyeing greenish-yellow shades because it contains the green and a portion of the blue as well as yellow.

No. 3 of the same plate shows the spectrum of Tartrazine. This colouring matter dyes much redder shades than picric acid, and the spectrum shows why this is so, for while the red, orange, yellow and green are present, the blue and violet are completely absorbed. The red and green constituents of these colouring matters, when they enter the eye, give rise to the sensation of yellowish-white; hence we perceive only the appearance of yellow, of a reddish tint, on account of the greater predominance of red and green rays over those of the former colour.

No. 4, Plate I., represents the spectrum of Scarlet R. We have here the complete extinction of the violet, blue, green and yellow portions of the spectrum, leaving only the red and the orange. As a contrast to this we have another red dye, Azorubine, shown in No. 5; this dye-stuff produces full crimson shades, and the reason is that only the red rays are permitted to pass through, while the rest are completely absorbed.

No. 6, Plate I., is the spectrum of a light shade of Magenta. In this case the rays absorbed are the yellow, green and greenish-blue; but in dark shades of Magenta there is more complete absorption, and only the extreme red rays are permitted to pass.

In No. 7, Plate I., we have the spectrum of Safranine; in

this there is absorption of the yellow, green, and a portion of the blue rays, with partial absorption of the violet, the whole of the transmitted rays imparting to the eye the impression of a violet-red, which is the hue peculiar to Safranine.

No. 8, Plate I., is the spectrum of Rhodamine, which dyes pink shades. The spectrum shows the reason of this as Rhodamine absorbs only yellow, green and green-blue rays, while the violet and red rays transmitted give rise to the sensation of pink to the eye.

Another red dye-stuff, the spectrum of which is given in Plate I., No. 9, is Eosine, shown in a dark shade, which indicates the transmission of red, orange, and a small portion of the yellow. In light shades there is absorption of the green and greenish-blue only, the other colours being transmitted.

In No. 10, Plate I., is shown the spectrum of Acid Green. The green and green-blue rays only are transmitted, while all the other rays are absorbed.

In No. 11 on the same plate is the spectrum of Indigo extract. Here the blue, bluish-green, part of the red and small portions of the green and yellowish-green rays are transmitted, the orange, yellow and violet being absorbed.

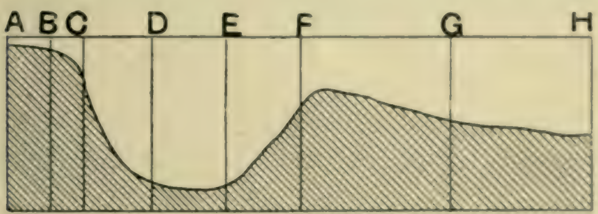
No. 1, on Plate III., is the spectrum of another blue dye-stuff, Cyanol, which dyes an extremely pretty blue. It shows the transmission of the green, blue, part of the violet and a small part of the red rays, the sum total of which gives rise to the sensation of blue to the eyes.

In No. 2 of the same plate we have the spectrum of Aniline Blue. This shows a transmission of a portion of the red, some of the green, all the blue and part of the violet rays, while the orange, yellow and extreme violet rays are absorbed.

No. 3, Plate III., is the spectrum of Methyl Violet, which shows the transmission only of the extreme red, part of the blue and part of the violet rays, the rest being absorbed.

No. 4, Plate III., is the spectrum of Iodine Green. It shows absorption of part of the red, orange, and yellow, and of the blue and violet rays.

It is the custom of dyers to mix dye-stuffs together for the purpose of obtaining certain shades: thus, for instance, Indigo extract and Picric Acid are employed to produce green. Now this green is produced, not because in the abstract blue and yellow produce green, but because they both allow green light to pass through, the Indigo extract absorbing the red and the yellow rays, and the Picric Acid the blue and the violet rays; thus only the green rays are



NAPHTHALENE RED

FIG. 24.

permitted to pass. A mixture of Methyl Green and Methyl Violet produces a blue; this is because blue is the colour common to both dye-stuffs. The Violet absorbs the green and yellow, while the Green absorbs the red and the violet; thus the blue only is transmitted. The combination of Azorubine with Acid Green produces a black; an examination of the spectra of the two colours shows why this is so, inasmuch as the Azorubine permits only the red to pass through, while the Green transmits only the green and blue rays. When both colouring matters are used together no rays pass through, the result is the production of a black: this proves that black is the result of the absence of light, and is not produced by the addition of one coloured light to another.

Fig. 24 is the spectrum of Naphthalene Red. This product dyes bluish-red tints, and the reason is visible from an examination of the spectrum, which shows the transmission of the red rays, together with a little of the violet, some of the blue, and a small quantity of the yellow.

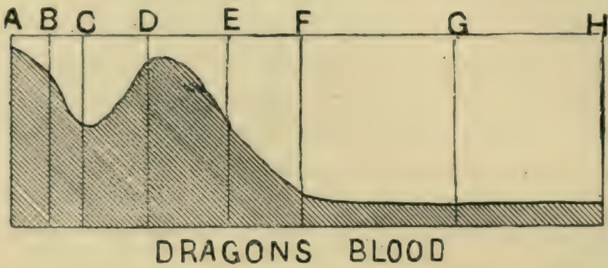


Fig. 25.

Fig. 25 is the spectrum of Dragon's Blood, which shows the transmission of the red and the yellow rays, and but a small quantity of the green, blue and violet.

The spectrum of Turmeric, a yellow dye-stuff which produces somewhat orange shades, is shown in Fig. 26.

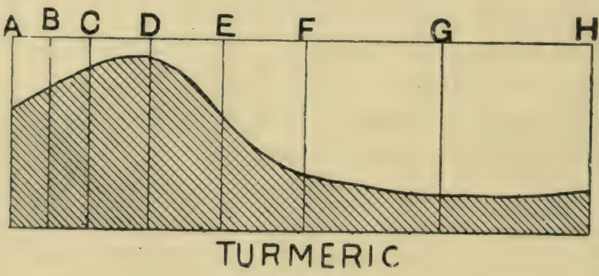


Fig. 26.

Here we see that yellow forms the principal portion of the transmitted rays; some of the red and the lighter greenish-yellow rays are also transmitted.

Figs. 27 to 29 show the absorption spectra of certain alcoholic solutions of various colouring matters. Alizarine,

Fig. 27, shows transmission of the red, orange and yellow, with a little of the green and but a small quantity of the blue and violet. The sister colour, Purpurin, which dyes somewhat bluer shades than Alizarine, has the absorption

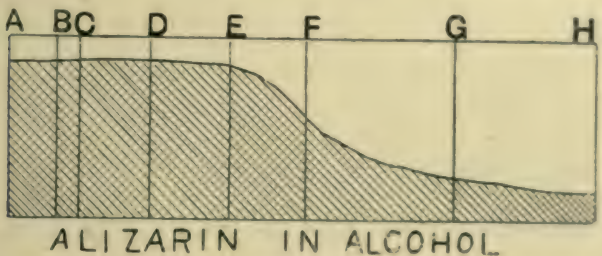


FIG. 27.

spectra shown in Fig. 28. Cochineal solutions, Fig. 29, show the transmission of red and blue rays, while only the green are absent to any extent.

The principal difficulty in colour phenomena is to account for the production of such shades as browns, olives, greys

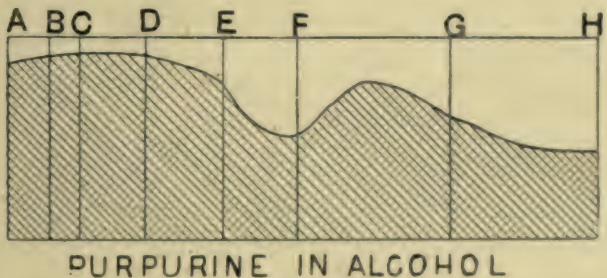
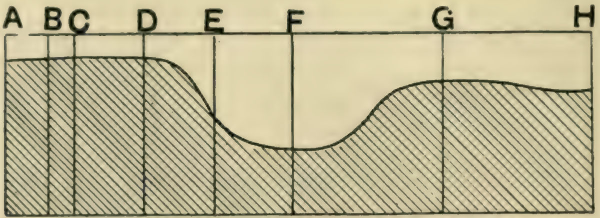


FIG. 28.

and similar shades, which often pass under the term of *tertiary* colours. An examination of the absorption spectra of such shades solves the difficulty. For instance, Bismarck Brown, which dyes cotton in reddish-brown or orange-brown shades, has a spectrum which shows both red, orange-yellow and green shades, this spectrum being very similar to that

produced by an orange colour; there is, however, much more diminution in the intensity in those portions of the spectrum, in other words, the luminosity of the spectrum of Bismarck Brown is much less than that of an orange dye:

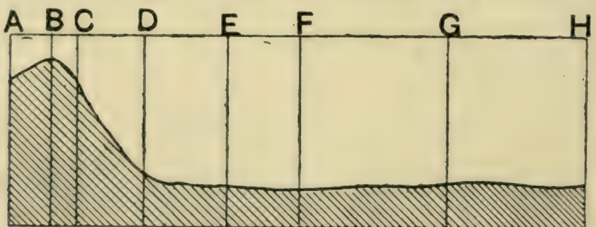


COCHINEAL IN ALCOHOL

FIG. 29.

we may regard Bismarck Brown as a poor or degraded orange without much error.

It is a common feature in dyeing to produce olive by using a mixture of Acid Green and Orange G. If the spectrum of the olive colour is examined, it shows only a



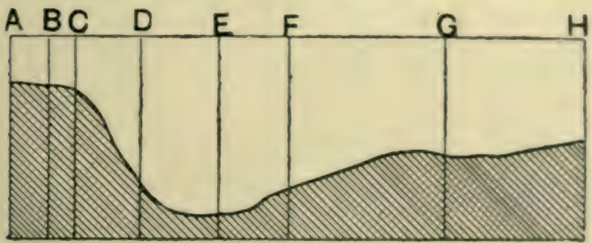
VERMILION

FIG. 30.

small portion of the green in very diminished intensity; therefore we may regard olive as a degraded green.

Greys are produced in dyeing by mixing red, yellow and blue dye-stuffs in various proportions. When the spectra of these shades are examined they usually show the presence of two points of light, one in the red and the other in the bluish-green. Now red and green together produce the

sensation of white; but owing to the considerable degree of absorption there is a very low luminosity, which appears to the eye as a grey; its production in this way is equivalent to mixing a black and white together, the shade of grey

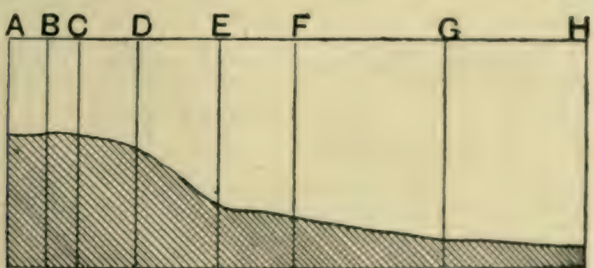


CARMINE

FIG. 31.

produced depending on the relative proportion of the dyes used.

Pigments, also, give absorption spectra, which may be exhibited in two ways, either by the light that is reflected from them, or by the light that is caused to pass through a thin



INDIAN RED

FIG. 32.

layer of the material. In either case, similar spectra are obtained. Figs. 30 to 42 show the spectra of the most common pigments used by painters. In Fig. 30 we have that of Vermilion, which shows that this pigment reflects the red and yellow rays and a small proportion of the other colours. In Fig. 31 we have that of Carmine, which differs

from that of Vermilion in there being a larger proportion of blue and violet rays; to which circumstance is due the crimson hue of Carmine. In Fig. 32 is given the spectrum of Indian Red. In this the red, orange and yellow rays are transmitted, also a small proportion of the blue and

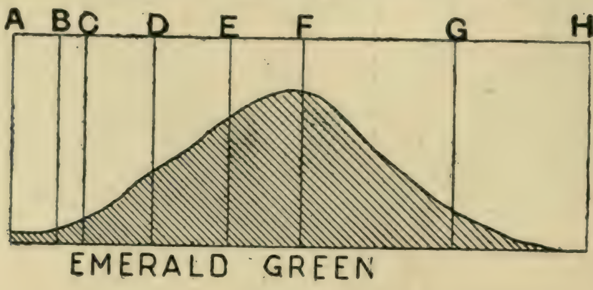


FIG. 33.

violet rays. It is somewhat of interest to compare the spectrum of Vermilion with that of Indian Red; the former pigment is of a bright scarlet colour, while the latter has a dull reddish hue. The spectra show that, while in the case of the Vermilion, the red and orange rays are transmitted in

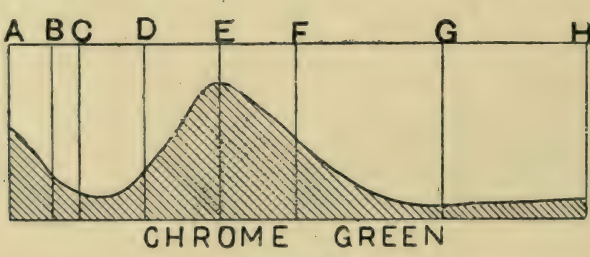


FIG. 34.

almost their full intensity, in Indian Red there is a very considerable loss in intensity in these rays, and it is to this circumstance that the much duller colour of that pigment is due. In Fig. 33 is given the spectrum of Emerald Green, from which it will be seen that while the green rays are present in almost their full intensity, there are present small

proportions only of the other rays of the spectrum. In Fig. 34 is given the spectrum of Chrome Green, where we have the green rays in nearly their full intensity, but there is also reflected a portion of the red rays and some of the blue

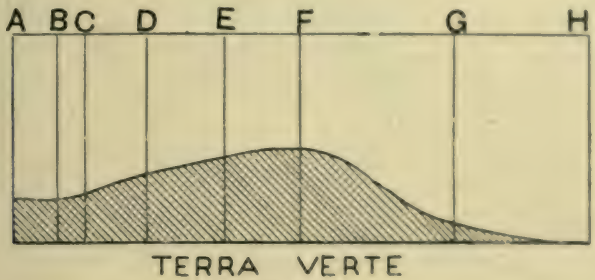


FIG. 35.

and violet rays, and it is to the presence of these latter shades that we must ascribe the duller tone of Chrome Green in comparison with Emerald Green. In Fig. 35 we have the spectrum of Terra Verte; this colour is more renowned for its permanence than for its brilliancy. Its hue is that of a

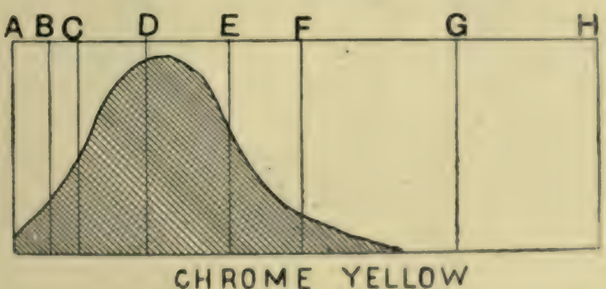


FIG. 36.

greyish-green; from the spectrum we gather that while the green rays are present, there is also a fair proportion of the red, orange and yellow rays as well as a little of the blue and violet rays; the intensity of all these rays is, however, very slight; this low intensity and the combined action of the

blue and red rays, when viewed by the eye, cause Terra Verte to appear of a greyish hue.

In Fig. 36 we have the spectrum of Chrome Yellow. It shows that this pigment reflects a large proportion of the

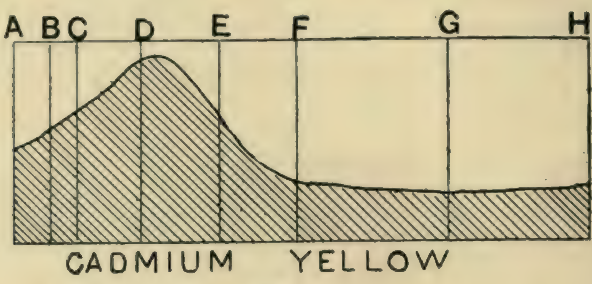


FIG. 37.

yellow and green rays, with a small quantity of orange and blue. Cadmium Yellow is a pigment of a rather more orange tone than Chrome Yellow. This fact is explained by examination of its spectrum, given in Fig. 37, which shows

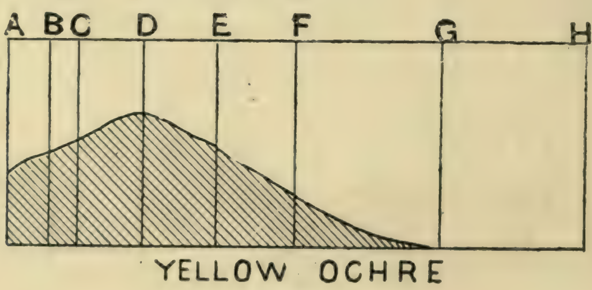
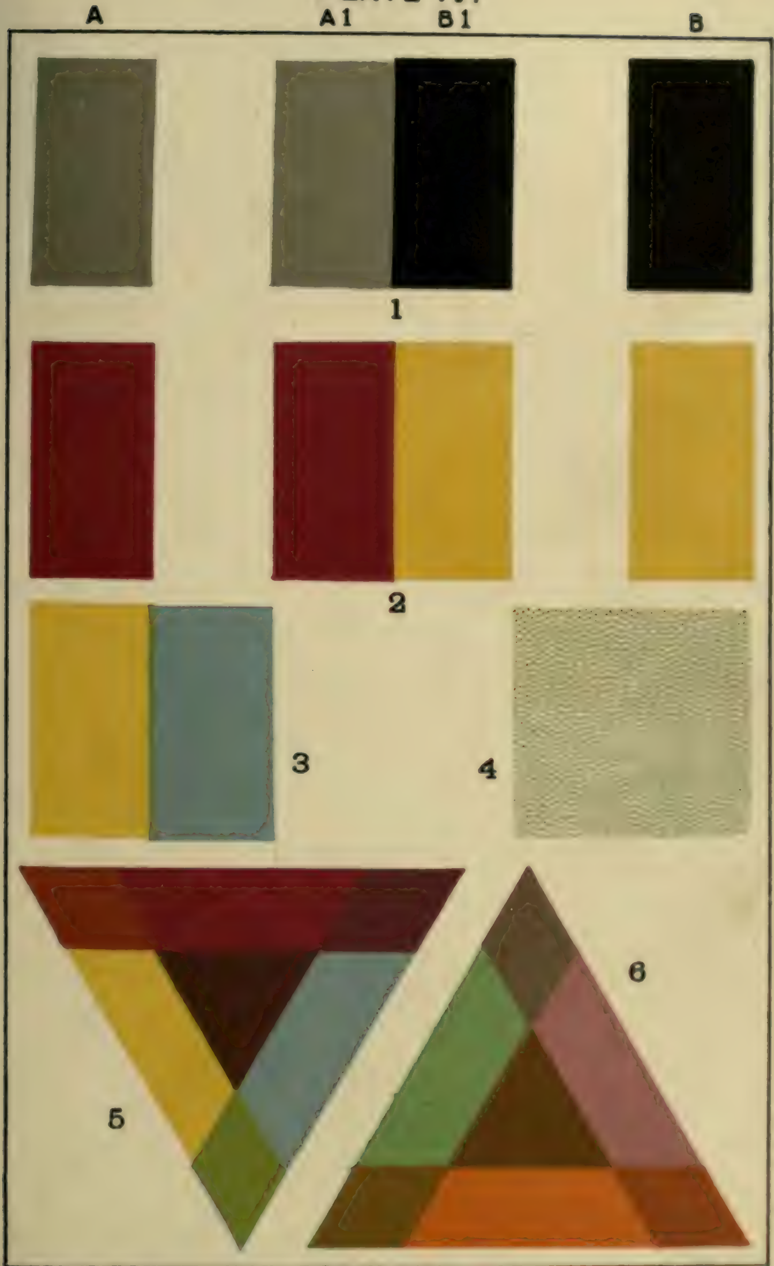


FIG. 38.

that, while yellow rays are strongly represented, there are also more violet and red rays than in Chrome Yellow.

The spectrum of Yellow Ochre is seen in Fig. 38, which shows the presence of yellow, some red, and a little green; the intensity of the rays is small as compared with Chrome Yellow, and to this fact the dull hue of Yellow Ochre is to be

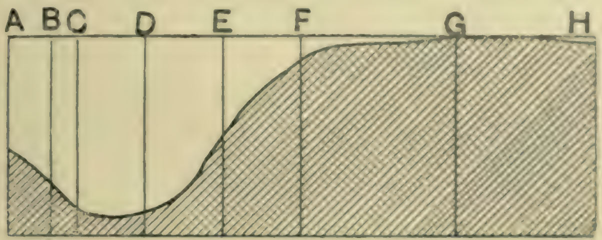
PLATE IV.



(THEORY OF COLOUR). Effect of Mixing Colours. *To face p. 48.*

ascribed, while the greater proportion of red reflected accounts for its reddish hue.

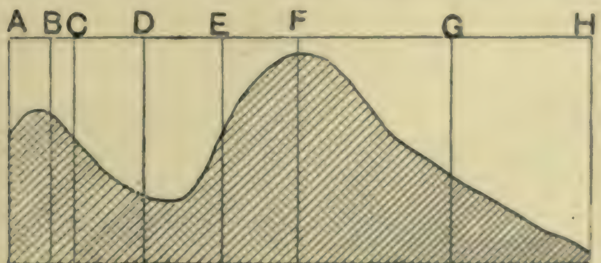
In Fig. 39 we have the spectrum of Ultramarine, a pigment of a bright hue. We see that, while there is a small quantity of the red and yellow rays, there is a great predominance of



ULTRAMARINE
FIG. 39.

the blue and violet rays to which the colour of the pigment is due.

Ultramarine Green is shown in Fig. 40, where we see the green rays are in the greatest predominance, while there is



ULTRAMARINE GREEN
FIG. 40.

only a small proportion of the blue and orange rays of a low intensity.

In Fig. 41 we have the spectrum of Smalt, which is a blue pigment of a violet hue and low intensity. The spectrum shows that almost every ray of colour is present

in greater or less quantity, and that the red, the blue and the violet rays are much more prominent than the other rays. The blue colour of this pigment is evidently due to the fact that the red and green on the one hand, and the

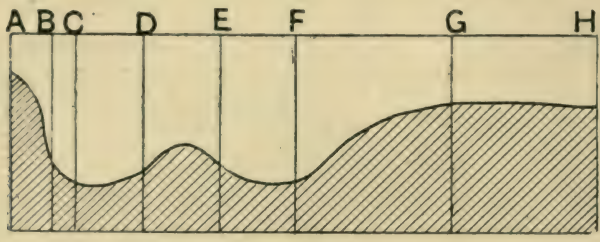


FIG. 41.

blue and yellow on the other, are present in just the proportions required to produce white light, leaving the violet and a portion of the blue to impress themselves on the eye. The low intensity of the colour is due to only a portion of each colour being transmitted.

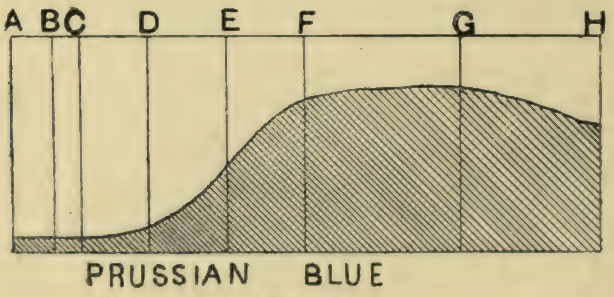
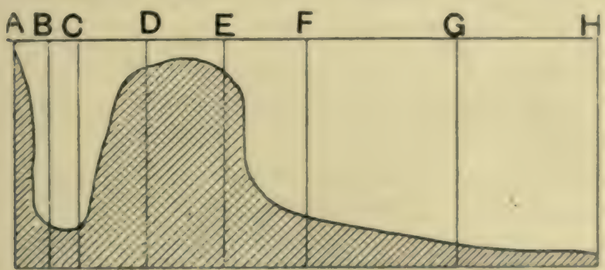


FIG. 42.

The well-known pigment, Prussian Blue, has a spectrum (Fig. 42) of a different character to either Ultramarine or Smalt. In this the blue and green rays have a greater predominance, the violet is also present, but there is little of the yellow or red rays. The deep colour of Prussian Blue is undoubtedly

due to the fact that the principal rays are transmitted in almost their full intensity.

We may conclude this section of the subject by an examination of the green colouring principle to which vegetation owes its hue, *i.e.* Chlorophyll. An examination of the spectra of the green colours which have already been given will show that with them the red is absent or nearly so, and the blue and violet are present in very small quantities. In Chlorophyll, however, we have a different result: we find the extreme red of the spectrum present in almost its full intensity; the orange is nearly absent, while the yellow,



CHLOROPHYLL

FIG. 43.

greenish-yellow and green, are present in considerable amount, a small proportion of the blue and violet rays being also included (see Fig. 43). The hue of Chlorophyll presents itself to the eye as a yellowish-green, and the reason of this is that the red and a portion of the green combine to form white light, the remainder uniting to produce a shade of yellowish-green. The fact that the Chlorophyll of green leaves reflects some of the red rays may be seen in the foliage of trees, when illuminated by the setting sun, having a reddish appearance.

The study of absorption spectra such as those above described leads to one very important conclusion: that the

eye cannot distinguish the true character of any light, white or coloured, which may be presented to it, but observes them one and all as monochromatic in effect, although they are possibly polychromatic in structure.

It is a fact well known to painters that the appearance of a pigment depends very greatly upon the particular vehicle or medium in which it is disseminated; this may be proved by an examination of drawings made in crayons, water colours and oil, using the same pigment. The explanation of this phenomenon is to be sought in the different manner in which the pigment or paint surface reflects the light that falls on it; in the case of a crayon drawing, and to a limited extent a water-colour painting, there is not only reflected the characteristic colour of the pigment, but a good deal of white light, the presence of which materially modifies the hue of the pigment as it is seen by the eye; in the case of water colours the presence of the very small proportion of gummy matter which is employed to fix the pigments is found to considerably reduce the quantity of white light which the pigment reflects, therefore we are much nearer to obtaining the true hue of the pigment, but there is less light reflected on the whole. When oil or varnish is used as the vehicle, the pigments appear to be much darker, the colour is richer, and there is found to be less white light reflected from the pigment. This change in appearance is due to the different conditions in which the light falls upon and is reflected from the pigment. With the dry pigment, as in crayon work and chalk drawings, there is a very considerable amount of white light reflected from its surface together with the characteristic colour rays, owing to the difference in the density of the air in which the light moves, and the surface from which it is reflected. In the case of water colours, or pigments immersed in water, the conditions are somewhat different, the light moving in a dense medium and being reflected from a pigment

which is in one sense only slightly more dense than the liquid; hence there is but little white light reflected, and the coloured light which is reflected is distinctly purer, the appearance of the pigment becoming richer. In the case of paintings in oils we have a medium which is of the same density as the pigment, consequently there is very little white light reflected from its surface, therefore the colour appears darker. This is particularly noticeable with Prussian Blue, which, used by itself in oil, appears of a blue-black colour; it is only when spread out in very thin layers on a white surface, or mixed with a white pigment, that the proper blue hue of Prussian Blue manifests itself. This change of colour is also noticeable with other pigments: ochres or natural earths, which appear of a pale hue in the dry state, when mixed with oil seem much darker and more richly tinted.

This change in appearance of pigments when mixed with media has a very important influence on their use in painting, so that between the extremes of drawings in crayons and chalks and oil painting we have various intermediate qualities. In oil painting the colouring is characterised by its richness and the transparency and depth of the shadows; while in crayon drawing the colours obtained are much paler, the shadows are much less intense, while a harshness pervades the whole drawing.

In fresco drawing or painting the artist is troubled by this change of appearance of pigment due to the difference of conditions in the media, for he has to work with a wet medium, which imparts to the pigments considerable depth of colour, while the finished picture is observed when the medium has evaporated, consequently its effect on the pigments is lost, the colours then having lost much if not all their brilliancy. The artist has necessarily to be on his guard to make allowance for this change, which renders fresco painting one of some difficulty; for this reason few artists are successful in pro-

ducing fresco drawings which are wholly satisfactory as regards harmonious colouring and uniformity of hue.

We may assume from the study of the absorption spectra of pigments, etc., that coloured bodies owe their colour to the selective power they exert on the rays of light which fall upon them, quenching or absorbing some, reflecting or transmitting others; the colours which they show depending upon the character and intensity of the rays which are transmitted.

CHAPTER III.

COLOUR PHENOMENA AND THEORIES.

DYERS, painters and others who use colouring matters of various descriptions are well aware of the fact that, by the use of a few of these colouring matters, they are able to produce a great variety of colour effects: thus, for instance, the painter with red, yellow and blue pigments, can produce a great variety of other colours and tints. The same may be said of a textile colourist; for instance, by mixing a red and a yellow, orange can be produced, but by using these two colours in various proportions he can produce an infinite variety of tints of orange, ranging from an extreme orange-red to a very yellowish-orange. Again, by mixing a blue and a yellow together, an infinite variety of green shades, from a yellowish-green to a bluish-green, may be produced; while the admixture of blue and red in various proportions will produce various tints of purple and violet; then by mixing the three colours, red, blue and yellow together an infinite variety of olive, sage and brown shades (which are known to the painter as sad shades) or even black may be produced. This fact, known to colourists for many years, formed the foundation for that theory of three primary colours— red, yellow and blue—which owing to the fact that Dr. Brewster was the principal exponent of it, has been known as the Brewsterian theory of colours. He considers that there are three fundamental colours,—red, yellow and blue— and that by the admixture of these three colours all other colours can be produced. This theory has,

however, been shown by several physicists—Thos. Young, Helmholtz, and others—to be erroneous, it has therefore given place to a much more correct theory, although we may say in defence that it explains very well the phenomena which occur on mixing colouring matters together.

Before passing on to the consideration of theories of colour, it may be well to consider some of the results that are obtained by mixing various colours together. In mixing colours it is well to distinguish between the mixture of colouring matters, dyes and pigments, and the mixture of coloured lights. It will be more convenient to deal with the latter phenomena first, noting the effects which can be produced by mixing coloured lights, and the means by which these colour mixtures can be produced.

FIG. 44.

One very well-known method of making experiments with mixtures of coloured lights is by means of a revolving disc, the experiment being that of Newton's disc, with which every student of light is familar. A white cardboard disc is painted in segments with different colours along its radius (Fig. 1, Plate II.), on rotating this rapidly, by the influence of the phenomenon known as persistence of vision (which will be fully discussed in the chapter on the physiology of light), the colours blend into one another, and a uniform whitish or greyish-white colour is produced.

Fig. 44 represents a very convenient rotatory apparatus,

consisting of an electro-motor driven by a galvanic battery of any convenient kind. The discs of cardboard are attached to the spindle of the electro-motor, which is so arranged that they may be changed as required. Fig. 45 is a drawing of Rothe's apparatus for rotating the colour discs. In this apparatus a variety of speeds may be obtained, varying from slow to very quick, by driving as may be desired, from the pulleys 1, 2 or 3: if 3 be made the driving pulley, then a slow speed is obtained; if No. 1 is used, then a quick speed is the result. If, instead of the Newton's disc, a disc painted one half blue and the other half yellow is employed, on rotation we shall obtain the sensation produced by mixing blue and yellow lights to-

FIG. 45.

gether, that is a white and not a green. The white may not, however, be quite pure, but may be more or less tinted with blue or green, because it is extremely difficult to proportion exactly the blue and yellow in this method of working. A better plan is that devised by Maxwell, who took two or more discs, each painted with a desired uniform colour; then, by making in each a slit from the centre to the edge, he was able, as shown in Fig. 46, to place them together and produce a combined disc showing any desired proportions of colour; thus it is possible, when using blue and yellow, either to expose more yellow or more blue, as the results on rotating the disc show to be desirable. Fig. 47 shows the rotatory apparatus with these discs in position; with their aid it is quite possible to study

combinations of two, three, or even more colours. By changing the proportion of blue to yellow a position is reached when on rotation we obtain a greyish-white; whatever the pro-

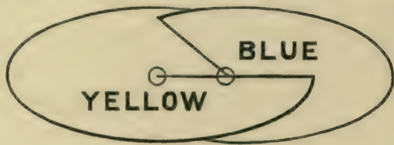


FIG. 46.

portions of the blue and yellow in these experiments, in no case is a green obtained.

Another method of combining coloured light is to place

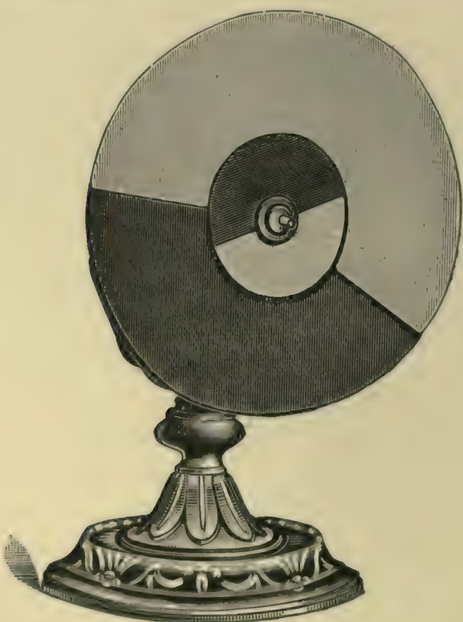


FIG. 47.

two sheets of the desired colours side by side on the table, and then to place a sheet of glass upright between the two patches of colour; on looking through the glass at one of the patches

we also see the reflection of the other, the sensation visible to the eye, however, is not that of the two colours separately, but the combined sensation of the two. By changing the position of the patches it is quite possible to view them as though they overlapped, we are then able to see the effect of the colours being combined together as well as separately: in the case of blue and yellow patches, white is always the result of the union.

Another method of mixing colours is by means of Dove's dichroiscope, a section of which is shown in Fig. 48. This consists of a box, ABCD, with an open back, BD, in which can be fixed a piece of coloured glass, and an open top, AB.

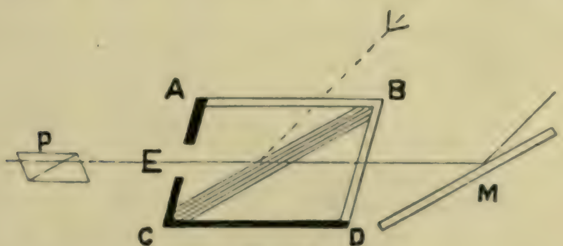


FIG. 48.

on which a piece of coloured glass may also be placed; while arranged diagonally from the front to the back are a number of glass plates, CB. If now the eye be placed at the aperture, E, coloured plates being on the top and at the back of the box, then the light passing from the mirror, M, through the glass, BD, and direct through the glass plates, BC; the light which passes through AB will at the same time be reflected from the surface of the plates, BC, and will also reach the eye, so that the eye receives two colour sensations, one from BD, the other from AB, but, as it is impossible to distinguish the two, one colour effect only will be observable—what this colour effect is will depend upon the colours of the two glass plates; not only so, but also upon the relative proportion of the two

colours. By taking advantage of the fact that the light passing through the instrument is more or less polarised, then by observing through a Nicol's prism, P, instead of direct, we can adjust the relative proportions of the two colours. By rotating the Nicol's prism more or less we find that, for instance, red and green glass will infallibly give a yellow varying from orange-yellow to greenish-yellow, according to the proportions of the red and green. Blue and yellow glasses give white, green and purple give also white, red and yellow give orange, green and yellow yellowish-green, and blue and red purple to violet, the tints of the mixed colour depending upon the hues of the glasses which are employed; a little care is, however, needed in selecting the glasses to give the best possible effects.

Advantage may also be taken of the fact that calcspar is double refracting and therefore gives two images of an object of equal intensity; if now a small screen of cardboard has two small apertures cut in it, these apertures can be covered with pieces of stained glass; these viewed through an achromatic prism of calcspar, yield two images of each glass, four images altogether. By careful arrangement it is possible to arrange for one image from the two glasses to fall on the same spot; then we get the colour effect of the two colours combined, while there are also separate images of each colour for comparison. The colour effects so obtained are the same as given by Dove's dichroiscope described above.

For showing colour phenomena on a large scale two optical lanterns may be employed, both arranged so as to be focussed on the same portion of the screen, while the use of stained glass or coloured gelatine films will give the desired results.

The following are a few results which the author has obtained on experimenting with Maxwell discs. Using ultramarine and a deep yellow disc in equal proportions, combinations which have a reddish hue were produced; altering the

proportion to 150 of ultramarine and 210 of deep yellow, a reddish-white tint appeared. If, in place of a deep yellow, we use a pale shade of yellow, then, if the proportions of the two discs are equal, a creamy-white is obtained, while with 270 parts of ultramarine and 90 parts of chrome a pale violet tint is produced. A mixture of 180 of vermilion and 180 of ultramarine produces a lilac rose tint, while 270 of vermilion and 90 of ultramarine gives a pinkish-red; or, if the proportions be reversed, 90 of vermilion and 270 of ultramarine, a blue-violet is produced. Using a mixture of 250 parts of Prussian blue and 110 of pale chrome we obtain a grey of a faint greenish tint. A disc of vermilion and green in about equal proportions produces a tint of a yellowish cast. In using these mixtures a great deal depends upon the depth of tone of the vermilion disc and that of the green disc, so the shade of the combined results may vary from yellowish to a pale brown. If the vermilion disc is in excess then a terra-cotta shade is obtained, while if the green disc predominates the hue becomes greenish; a combination of a vermilion disc with a yellow disc in equal proportions produces a deep orange shade, while if the vermilion predominates, an orange-red appears; vermilion and Prussian blue discs in equal proportions produce a dull greenish shade—an excess of the Prussian blue produces a deep lilac, while an excess of the vermilion produces a pale red. A disc of vermilion and one of emerald green produces a whitish-yellow; this of course is the result according to Young's theory. A disc painted with violet and one with yellow give a yellowish-grey, while a combination of a violet disc and a dark-green disc gives a greenish-grey. A disc coloured with carmine combined with one painted with green gives rise to a faint reddish tint.

The results thus produced are due to the effect of persistence of vision, while the pigments used are not pure colours (see the spectra Figs. 30 to 42), it is not to be expected that

the results of these colour experiments should be exactly those demanded by theory; they are vitiated by what may be termed errors of experiment. They show how wide is the difference between mixing the colour sensations themselves and mixing the pigments or colouring matters which have been used in the production of the discs; thus, a mixture of ultramarine with chrome yellow on the discs produces a reddish-white, while the same pigments mixed together produce greyish-green. Prussian blue and chrome yellow discs give a greenish-grey, a mixture of the two pigments gives a full green; vermilion and emerald-green mixed by the disc produce yellow, while in the form of pigments they give rise to a brick red. Vermilion and ultramarine mixed together by the discs give a faint rose tint, while as pigments they give rise to a purple colour.

We may also compare the results which are obtained by mixing coloured lights together with the Dove apparatus, with the calcite prism, and we may also compare these results with the effect produced by passing light through the two glasses and observing them with the eye. Thus a red glass and a green glass observed by the prism give rise to a pale yellow or to an orange colour according to the character of the red glass, while on looking through the two glasses placed together the colour appears dark-green to black. A yellow glass and a blue glass viewed with the prism appear white, which may possibly have a pinkish hue according to the exact tone of the two glasses; by direct observation these glasses appear to be green. A mixture of red and blue glass appears of a purple or violet in the apparatus, and of a deep red directly. Yellow and red glasses appear to be yellow or orange with the prism, and of a deep orange or red seen directly. A yellow and a blue-green glass with the prism appear of a yellowish-white colour, without, of a rich yellowish-green. A violet and a green glass with the prism may have a blue

colour, while without the prism they would appear to be black. From these results it will be seen that the effects obtained by mixing coloured pigments together, and those obtained by mixing coloured lights, are of a very different order. The difference is very marked in many cases, and the results obtained in one cannot be predicted from the other. Figs. 2, 3 *et seq.*, Plate II., show some of the results obtained with coloured lights which are allowed to fall one upon the other on a screen from two lanterns, and the colour obtained by two coloured glasses placed together in a beam of light. In Fig. 2, Plate II., we have the result of two discs, one of blue the other of yellow light, falling upon the screen from two lanterns—where they overlap it appears white. In Fig. 4 we have the same two colours thrown together on the screen from one lantern—where they overlap it is green. These differences of result are explainable in this way: In the first case we have both blue and yellow lights illuminating the same spot, and the illumination excites in our eyes the sensation of white. In the second case the light has already passed through one glass, say the blue, and been robbed of its red and yellow rays before it passes through the yellow glass, and this again exerts its absorbing effect, stopping the passage of the blue and violet rays which reach it, only permitting the green rays to pass through, so that green alone appears on the screen. In the second place we have in Fig. 3, Plate II., the effect of two discs, one of red the other of green light from two lanterns—where they overlap it appears yellow. This of course is in accordance with Young's theory of light. In Fig. 5, Plate II., we see the effect of the light passed successively through the red and green glasses, the result being the production of black. This is due to the fact that the red glass, through which the light first passes, permits only the passage of red rays, these on reaching the green glass are absorbed, black appearing as the result.

So far we have considered the mixture of colour sensations produced by transmission or reflection from artificial colours; it will now be as well to briefly describe the results obtained by mixing together coloured lights of a pure character, such as are got by means of either the spectroscope or the polariscope. It is quite possible to produce a spectrum by one spectroscope, and to project upon this any portion of a spectrum produced by another spectroscope; by an arrangement of the polariscope, as shown previously, overlapping images of two colours can be produced. Captain Abney has described an arrangement by means of three slits, which, placed in connexion with the spectroscope, is capable of allowing three portions of the spectrum to fall upon the screen at one spot. The apparatus can be so arranged that any portion of the spectrum can be examined at the same time; if with such an apparatus the slits are arranged in the red, the green and the violet, we have white light produced. If now the slit in the green is moved towards the red the tint of the mixture becomes more reddish; to still keep it white the slit in the red must be partially closed, until we find that, by having one slit on the yellowish-green and the other slit on the violet, we also are again able to produce white light. This fact tends to show that the yellowish-green rays are formed by the admixture of the red and the green of the original spectrum; it is also found that a mixture of red and a bluish-green produces white. In a similar manner we find that a mixture of orange and greenish-blue makes white, a mixture of yellow and blue makes white, a mixture of greenish-yellow and violet makes white, and of green and purple makes white. Putting these results in the form of a table for clearness, we have the following five combinations, any of which will produce white:—

Red and bluish-green.

Orange and greenish-blue.

PLATE V.

(THEORY OF COLOUR). Colour Contrasts. *To face p. 64.*

Yellow and blue.

Greenish-yellow and violet.

Green and purple.

In other words, white light must contain one of these five pairs of colours, in each case one colour is said to be complementary to the other, but these same results are obtained whether we use the spectrum lights or the lights of the polariscope.

The changes brought about by one colour falling upon another is of very great importance, it has some bearing on the employment of pigments and dyes in the production of paintings and designs for decorative purposes. Thus Rood has made a number of experiments on this question, and we may give his results here, in several cases they have been repeated by the author.

TABLE I.

Yellow light falling on paper painted with

Carmine gave	Red-orange.
Vermilion gave	Bright orange-red.
Orange[1] gave	Bright orange-yellow.
Chrome yellow gave	Bright yellow.
Gamboge gave	Bright yellow.
Yellowish-green[2] gave	Yellow.
Green[3] gave	Bright yellow-green.
Blue-green[4] gave	Yellow-green (whitish).
Cyan blue[5] gave	Yellow-green.
Prussian blue gave	Bright green.
Ultramarine blue gave	White.
Violet[6] gave	Pale reddish tint.
Purple[7] violet gave	Orange (whitish).
Purple[8] gave	Orange.
Black[9] gave	Yellow.

[1] Mixture of red lead and Indian yellow.

[2] Mixture of gamboge and Prussian blue.

[3] Mixture of emerald green with a little chrome yellow.

[4] Mixture of emerald green with a little cobalt blue.

[5] Mixture of cobalt blue and emerald green.

[6] Hoffmann's violet BB. [7] Hoffmann's violet BB and carmine.

[8] Hoffmann's violet BB and carmine. [9] Lamp black.

TABLE II.

Red light falling on paper painted with

Carmine gave	Red.
Vermilion gave	Bright red.
Orange gave	Red-orange and scarlet.
Chrome yellow gave	Orange.
Gamboge gave	Orange.
Yellowish-green gave	Yellow and orange.
Green gave	Yellow and orange (whitish).
Blue-green gave	Nearly white.
Cyan blue gave	Grey.
Prussian blue gave	Red-purple or blue-violet.
Ultramarine blue gave	Red-purple or blue-violet.
Violet gave	Red-purple.
Purple violet gave	Red-purple.
Purple gave	Purple-red or red.
Black gave	Dark red.

TABLE III.

Green light falling on paper painted with

Carmine gave	Dull yellow.
Vermilion gave	Dull yellow or greenish-yellow.
Orange gave	Yellow and greenish-yellow.
Chrome yellow gave	Yellowish-green.
Gamboge gave	Yellowish-green.
Yellowish-green gave	Yellowish-green.
Green gave	Bright green.
Blue-green gave	Green.
Cyan blue gave	Blue-green.
Prussian blue gave	Blue-green, cyan blue.
Ultramarine blue gave	Cyan blue, blue.
Violet gave	Cyan blue, blue, violet-blue.
Purple violet gave	Pale blue-green, pale blue.
Purple gave	Greenish-grey, grey, reddish-blue.
Black gave	Dark green.

TABLE IV.

Blue light falling on paper painted with

Carmine gave	Purple.
Vermilion gave	Red-purple.
Orange gave	Whitish-purple.
Chrome yellow gave	Yellowish-grey, greenish-grey.
Gamboge gave	Blue-grey.
Green gave	Blue-green, cyan blue.

Blue-green gave	Blue, cyan blue.
Cyan blue gave	Blue.
Prussian blue gave	Blue.
Ultramarine blue gave	Blue.
Violet gave	Ultramarine, violet-blue.
Purple violet gave	Blue-violet.
Purple gave	Violet-blue, purple-violet.
Black gave	Dark blue.

Incidentally there have been mentioned some of the colours which can be produced by the admixture of various pigments together. It will be as well if we devote more attention to this question and at the same time to the colours obtained by the dyer in mixing various dye-stuffs together. For instance, when chrome yellow and vermilion are mixed an orange is produced; when a yellow pigment and a blue pigment are mixed together a green is the result—this is noted with Prussian blue and gamboge, a very favourite mixture with artists; or Prussian blue with chrome yellow, which forms the Brunswick green of the house painter. The reason of a blue and a yellow pigment producing green and not white, as would have been the case with blue and yellow lights, is that Prussian blue reflects green light as well as blue light, which may be seen from its spectrum given on page 50, while the chrome yellow, as will be noted from its spectrum given on page 67, also reflects green as well as yellow.

In explaining this effect, it is usually stated that the blue rays of the one pigment and the yellow rays of the other pigment neutralise one another, allowing only the green rays to develop themselves, but it is really due to the combined absorptive action of the pigments on the light resulting in only the green rays being allowed to pass or reflect that the mixture of yellow and blue pigments produces green. When red and yellow pigments are mixed together, orange is the result, as stated above; in this case a similar result is obtained, inasmuch as we not only get an absorptive effect of the

two pigments on the light, the red absorbing all the rays from the violet to the green, and most of the yellow; the yellow pigment absorbing all the rays from the violet to the bluish-green, and most of the red—thus orange itself, part of the red and part of the yellow are the only rays not absorbed, the combined effect of red rays and yellow rays upon the eye is to produce orange, therefore orange is the predominating colour.

Again, when blue and red pigments are combined together, violet is the result; here again, as with the orange combination, we have not only the absorptive effect of the two pigments on the light, cutting off all but red, blue and violet, but also the physiological effect, inasmuch as when red and blue rays are both present they give rise to the sensation of violet.

But the character of the orange, green or violet which is produced largely depends upon the character of the red and yellow, yellow and blue, red and blue pigments which are used, as also upon the relative proportions of those which are present. Ultramarine, although a blue pigment, does not yield as good greens as Prussian blue; its tone approaches more nearly to a pure blue than that of Prussian blue, therefore it does not reflect so many of the green rays (see Figs. 39 and 42). Yellow ochre, again, does not produce good greens, but greyish tones. Carmine produces purer violets with Prussian blue than can be obtained with vermilion, because it reflects more of the violet rays than the latter pigment, as may be seen by a comparison of the spectra given in Figs. 30 and 31.

If a red pigment and a green pigment are mixed together, a brown is the result, this varying in tone or hue according to the relative proportions of the two pigments; brown is therefore really a resultant of a double effect, first the red and the green tending to absorb nearly the whole of the rays, only

permitting the red, orange and yellow to pass, but besides this there is a considerable decrease in the luminosity of the mixture, which has the effect of adding black, the result is that the colours are toned down, brown being produced. Mixing an orange and a green pigment has a similar effect, only the mixture is not so dark.

The dyer, like the painter, produces a great many of his effects by mixing various dye-stuffs together. Thus he gets brown by mixing a red, a yellow and a blue dye together, and by varying the proportions he can produce a great range of shades. By using Archil, Turmeric and Indigo extract he gets a brown, and a similar brown is got from Indian yellow, Aniline blue, and Orange 2; it is to be noted that the orange or yellow predominates in each case—by increasing the proportion of the blue, the brown becomes darker. The dyer is also accustomed to produce greys by mixing a red, a blue, and a yellow dye, as for instance a grey is obtained from Chromotrop 2R, Cyanine B, and Azo yellow. A spectroscopic examination of this mixture would show that together they absorb all the rays of the spectrum, for each acts so as to take out its own section of the rays, and therefore black results; the white of the fabric dilutes this to a grey effect. By increasing the proportion of the red, reddish-greys are obtained, while if the blue is increased then bluish-greys result, or if both the blue and the yellow are increased then a greenish-grey is obtained. Like the painter, the dyer gets his greens by mixing blue and yellow dyes together in various proportions, and occasionally he adds a little red for such colours as peacock green; thus, by using a mixture of Cotton blue, Acid yellow and Chromotrop, a peacock green can be dyed. Many of the modern coal-tar blacks have a bluish or violet shade; it is found that, by using a little yellow or green dye, the black is improved and becomes much purer. This is due to the fact that the addition of the yellow or green dye results in the

absorption of the blue light which the original dye-stuff allowed to pass through. Black can be dyed on wool by using a mixture of Naphthol blue, Indian yellow and Naphthol green: this black is produced as the result of these dyes absorbing the whole of the spectrum, and in allowing no rays to be reflected or transmitted. It is of course impossible to describe or to notice all the colour effects which may be obtained or produced by the admixture of different colouring matters, but it may be stated here that the dull effect of such dark shades as browns, olive-greens, etc., is due to their low reflecting power for light; on the other hand, in the case of light tints such as greys, lilacs, pinks, creams, we have the fibre, or rather the light reflected from it, also playing a part in the sensation developed in the eye. We shall have further to consider the effects brought about by changing the luminosity of light either by an increase or a decrease thereof.

The same colour may be produced by combining different dye-stuffs together; thus, for instance, a bright green may be got with indigo extract and Naphthol yellow, and also by using Naphthol yellow, Orange G and Acid green, but it does not follow that, although the tint of the two colours may be the same, they have quite identical properties; thus if subjected to various illuminants they may show slight differences of tints, and again the addition of other colouring matters may produce divergent effects; thus, while the addition of a red dye-stuff to one of the mixtures may produce a deep brown, with the other it may form a maroon. Again, the shade of blue produced on wool by indigo extract may be matched by daylight with a mixture of Naphthol yellow, Violet 4B, and Cyanol, but viewed by gaslight the shades are quite different. The addition of a crimson dye to the indigo may convert it into a bluish-black, while the same addition to the mixture may produce reddish-black. These differences in effect are due to differences in the absorptive action of the colouring

matters on the light—the eye, as it were, sees the mean of the rays of light which are transmitted or reflected, but it has no power of distinguishing what particular groups of rays are actually present, yet the character of the shades which may be produced by the admixture of various dye-stuffs together always depends upon the character of the rays which those dye-stuffs transmit or reflect, and not upon what is seen by the eye. It may be broadly stated that when dye-stuffs whose absorption spectra more or less overlap one another are mixed, then it is the overlapping portion which governs the shades which are produced. The larger this portion is, the brighter and more luminous will be the hue of the colour visible to the eye; the smaller the overlapping portions are the less luminous and duller will appear the shades. When dye-stuffs are used whose spectra do not overlap one another, then black will invariably ensue.

We may now devote some attention to the subject of primary and complementary colours. It has already been pointed out that the painter being able, using red, blue and yellow pigments, to produce all colour effects, led to the development of the Brewsterian theory of there being three primary colours—red, yellow and blue. This theory having a good many practical applications we will devote some attention to it. By the combination of two of these primary colours we get, as described, a series of three other colours, which are known as secondary colours, these being orange, green and violet—the orange from the combination of the red and yellow; the green from the combination of the yellow and blue; and the purple or violet from a combination of the red and blue. Then by the combination of these secondary colours together in pairs or with a primary colour, we get a series of other colours which are called tertiary colours. Coloured diagrams on Plate IV., and also Figs. 49 and 50, illustrate this theory of primary, secondary and tertiary colours.

The diagrams take the form of triangles, the sides of which are filled with a primary or secondary colour overlapping at the corners; the central portion is also filled with a colour, which is produced by the union of the three colours forming the plate. In the triangle in Fig. 49 are employed the three primary colours—at the top red, left-hand side yellow, and the right-hand side blue; the red and yellow overlapping at the top left-hand corner form the secondary colour orange, similarly

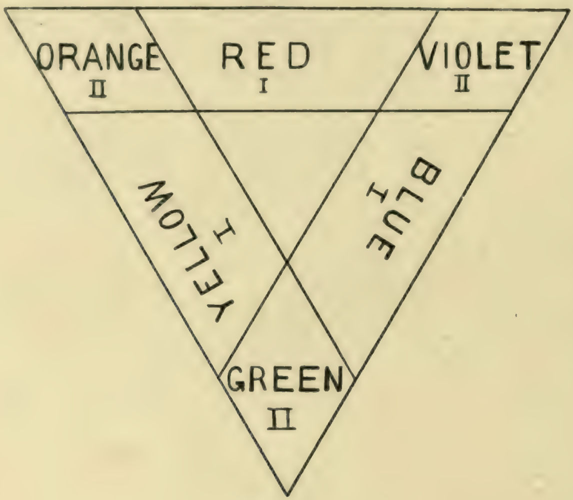


FIG. 49.

the red and blue overlapping in the top right-hand corner form the secondary colour violet, and the blue and yellow where they overlap at the bottom corner form green, while in the middle is a tertiary colour formed by the union of the three primary colours formed in constructing this diagram. In Fig. 50 we have the triangle formed from the three secondary colours; at the left-hand side is green, right-hand side violet, and at the bottom orange; where the green and the violet overlap at the top corner we have the tertiary colour commonly named slate; at the left-hand bottom corner we have

the green and orange overlapping when we get the tertiary colour named citrine; while at the right-hand bottom corner we have the violet and green overlapping forming the tertiary colour usually named russet. In the centre is a more complex colour formed by the union of the three secondary colours. The diagrams (Figs. 49 and 50) should be compared with the corresponding coloured diagrams on Plate IV. The combination between the primary and secondary colours to form the tertiary

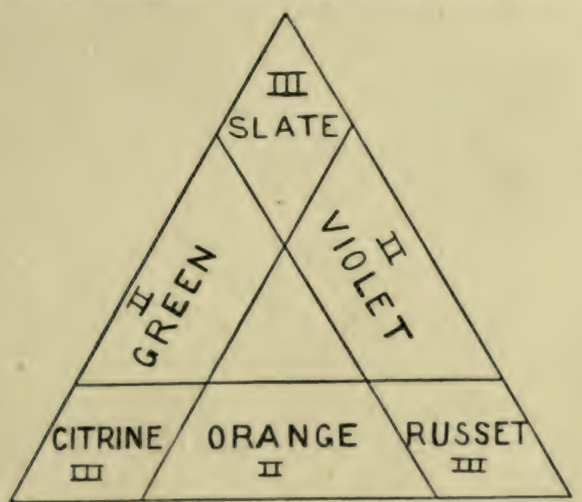


FIG. 50.

FIG. 50.

colours may take place in a great variety of ways, and consequently there can be produced a large number of shades of tertiary colours depending upon the relative proportions of the constituent colours from which they are formed.

The tone, tint, or shade of a colour are terms which are frequently met with in colour work, but they are somewhat indefinite, and are used by colourists rather indiscriminately. If a colour is mixed with a white pigment we weaken or reduce its tone; by using various proportions of the two (the colour and the white) we get quite a range of colours, these

are known as tints. By mixing black with the pigment we render it duller and produce shades as they are called. Thus we may have quite a scale or range of shades according to the relative proportions of the black and the pigment; we can therefore distinguish between tints and shades.

First, we have a reduced scale of tints made by mixing the colour with white.

And second, a darkened scale of shades which are produced by mixing the colour with black.

The tertiary colours are always more or less dull, this is to be accounted for by the fact that a mixture of the three primary colours should produce black, but in the tertiary colours one or other of these three primary colours predominates, and it is this predominating colour which produces the hue of the tertiary colour.

It has been found that, in mixing the primary colours, the best effects are not obtained by mixing the pigments employed in equal weights, but rather in what may be called equivalent proportions: thus, it has been found that three parts of yellow require five parts of red to make a good orange; in the same way it has been found that three parts of yellow require eight parts of blue to form a green, and that eight parts of blue are able to combine with five parts of red to form a violet. These numbers three, five and eight are considered to be the equivalents of yellow, red and blue respectively; but too much stress must not be laid on these colour equivalents, for they vary with the particular pigments which may be used; however, they will occasionally serve a convenient purpose. By proportioning the red and yellow, yellow and blue, or blue and red, we can produce a variety of tints of the secondary colours: these we may represent in the following manner, using the letters R, Y and B for the three primary colours:—

$Y + R =$ Orange.
$2Y + R =$ Yellowish-orange.
$Y + 2R =$ Reddish-orange.
$R + B =$ Violet.
$2R + B =$ Reddish-violet.
$R + 2B =$ Bluish-violet.
$B + Y =$ Green.
$2B + Y =$ Bluish-green.
$B + 2Y =$ Yellowish-green.

COMPLEMENTARY COLOURS.

It has been shown that when two coloured lights are mixed together white light is produced. This statement is only true of certain combinations, such as blue and yellow, and green and purple (see page 65); such pairs of colours are said to be complementary to one another. We find that a knowledge of pairs of complementary colours is of considerable importance from the artistic point of view, inasmuch as the colours thus paired appear of the greatest possible contrast to one another, while at the same time they harmonise more together than any other combinations—as, for instance, a red design on a green ground shows up much more distinctly and harmonises better than a red on blue or a red on violet. Similarly a yellow design on a blue ground shows up much more strongly than a yellow design on a green ground.

All the spectrum colours are primary, and each of them has its own particular complementary colour situated in some other portion of the spectrum. We may give here a table of the complementary colours of the principal divisions of the spectrum :—

TABLE OF COMPLEMENTARY COLOURS.

Red	Bluish-green.
Orange	Deep-blue.
Yellow	Ultramarine blue.
Greenish-yellow	Violet.
Green	Reddish-violet.

Many other pairs could be formed. The colours which lie between the red and the orange have their complementary colours between the bluish-green and cyan blue. The colours which lie between yellow and green find their complementary colours in the portion lying between the ultra-marine blue and the reddish-violet.

The best plan of studying the production of complementary colours is by means of the polariscope arranged in connection with selenite plates of varying thickness, to produce discs of colour such as those shown in Figs. 5 to 8 on Plate III. It is the best way of producing complementary colours, and gives by far the most satisfactory results. It is impossible in words to convey an idea of the exact shades of the pairs of colours which are complementary to one another. It is not always easy to match them by painting, but it is only in this way that a meaning can be conveyed.

The polariscope does not, however, give us the complementary colours of many tints which can be produced by pigments and of which it is desired sometimes to know the complementary colours. This is especially the case with olive-green, brown, and other shades of a similar character. This is due to the fact that the colours, obtained by the polariscope in conjunction with selenite, are very largely diluted with white light, which considerably increases their luminosity, whereas the colours referred to have a very weak luminosity. We can, however, obtain a solution of this problem by means of the Maxwell discs, by taking advantage of the fact that the rotation of two primary colours tends to produce a grey; if we take the colour which we require to match, and employ other discs, arranged so that with other primary colours they will produce a grey. Such a combination is shown in Fig. 51, where we have a combination of three large discs—a red, a green, and a blue; and two small discs—one black and one white. The black and white when rotated give the sensation

of grey. Red is the colour which it is desired to match, then by mixing green and blue in certain proportions and rotating the discs we get a grey matching that of the central discs; the colour produced by combining green and blue is therefore complementary to the red. Again, Fig. 52 shows the manner of producing a complementary colour to a yellow ochre; the yellow required more blue than green to obtain a grey identical to that produced by the rotation of the black and white discs.

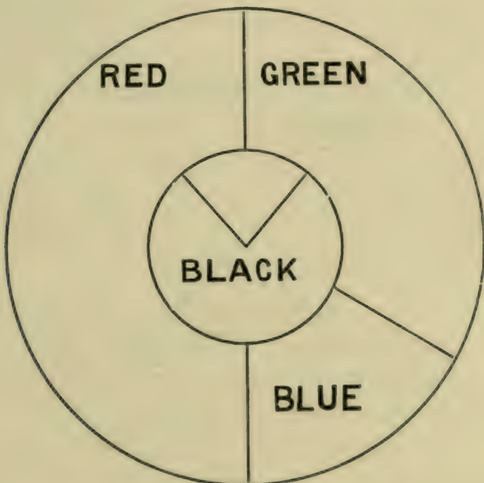


Fig. 51.

Even this method is not altogether satisfactory, for the relative intensities and luminosities of the pigments used in the production of the discs have a considerable influence in modifying the results. It is only possible to obtain the true complement of a colour by combining it with other colours having equal degrees of intensity and luminosity. Unfortunately this is rarely the case, as the red and yellow pigments—carmine, vermilion, chrome yellow—are much more luminous than the green and blue pigments—emerald green, cobalt blue,

ultramarine—which can be employed in this method of producing complementary colours.

In painting, and also according to the Brewsterian theory of colour, the term complementary is employed in another sense. According to the theory there are three primary colours—red, blue and yellow. Now by mixing these three together we get three other colours, orange from the yellow and red, green from the yellow and blue, and purple or violet

FIG. 52.

from the red and the blue. These are called secondary colours, and each secondary colour is considered to be complementary to the primary colour which is not used in its production; thus, green is regarded as complementary to red, blue to orange, yellow to violet. This is illustrated in the coloured chart Fig. 5, Plate IV., which depicts a triangle each side of which is occupied by a primary colour, while at the tips the colours overlap to form the secondary colours. The primary on one side is complementary to the secondary in the corner opposite to it. The coloured triangle No. 6, Plate IV., shows

in a similar way the secondary colours, orange, green, and violet, and at the corners the tertiary colours formed from them, each of the latter being complementary to the secondary facing it, slate to orange, citron to violet, russet to green.

SUPPLEMENTARY COLOURS.

This is a term used in some text-books to indicate the colour which is left when two of the primary colours are taken from any combination. It is, however, a term which is extremely vague in its derivation and use.

Colour Theories.—Having discussed at length the phenomena of colour production and admixture it will now be convenient to consider some of the theories which have been propounded from time to time to account for these phenomena.

Brewster's Theory.—This theory has several times been referred to in connection with primary and secondary colours, and its bearings have already been adequately discussed. The red, blue, and yellow primary theory fails, however, to account for all the colour phenomena which can be produced, chiefly because it was not based on an examination of the composition of coloured lights.

Young-Helmholtz Theory.—Thomas Young was the first to point out that Brewster's theory did not explain the results which can be obtained by mixing the spectral colours together, nor the effects which can be got by means of the revolving Maxwell discs. He therefore propounded the theory of three primary colours consisting of red, green and blue; this theory, more fully developed by Helmholtz, is known as the Young-Helmholtz theory, and, seeing that it explains in a fairly satisfactory manner all colour phenomena, it has become almost universally accepted as being correct.

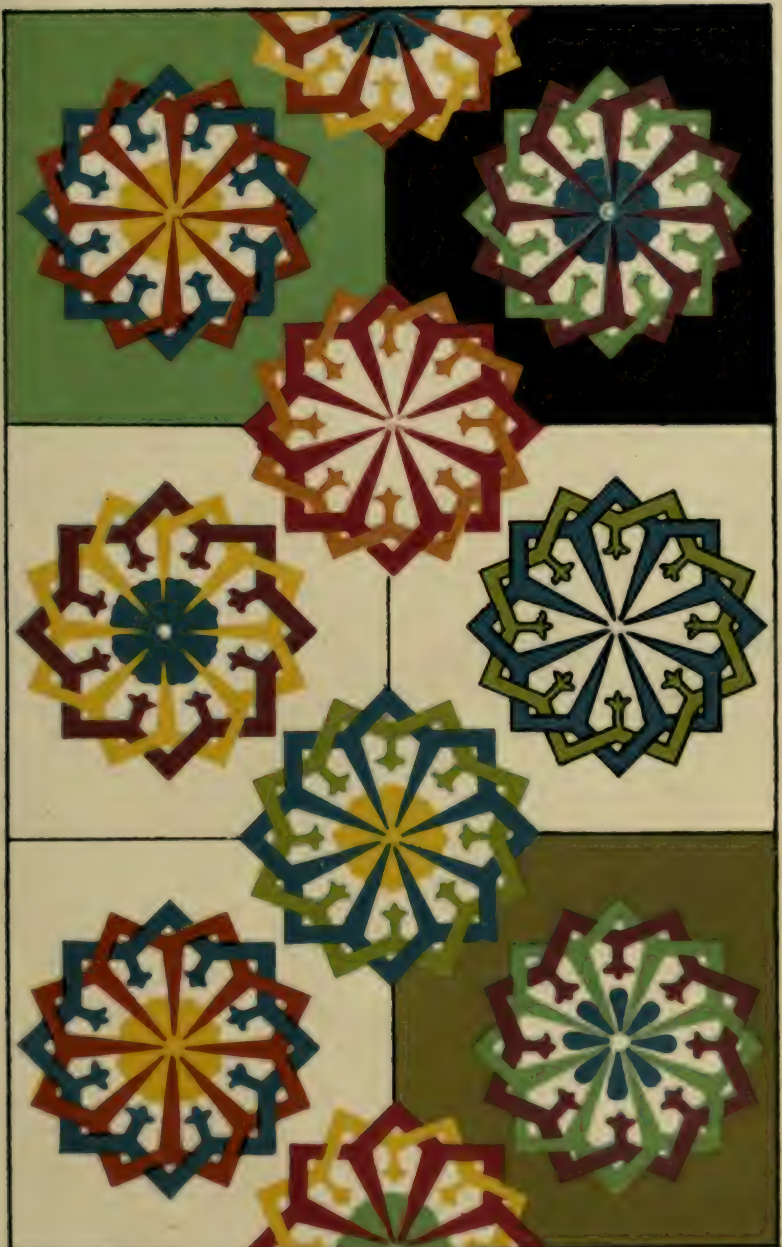
According to this theory the three primary colours are red, green and blue. Now as there are various hues of

these colours, some difference of opinion naturally exists amongst colourists as to the exact hue which should be adopted as a true primary colour, particularly as regards the blue. The primary red is usually accepted to be one having about the same hue as carmine or a mixture of equal proportion, of carmine and vermilion, the green resembling emerald-green in hue, being perhaps a little deeper in tone, the blue approaching the tone of Prussian blue. Some colourists are inclined to regard the true primary blue as being a little greener in tone than Prussian blue, while others, Maxwell and Müller, consider the primary blue as one having a more violet hue, like ultramarine.

When two of these primary colours are mixed together secondary colours are obtained; thus red and green yield yellow, green and blue give a greenish-blue, named sea green, while red and blue give a purple tint. It will be noted that on mixing two of these colours we get the tint which occupies an intermediate position in the spectrum. When the three primary colours are mixed together we get white light. It is, however, necessary to point out that the results which are here stated to be obtained can only be got with spectrum colours or the colours obtained with the polariscope; only an approximation can be obtained with coloured lights thrown from several sources on a screen (see Plates No. II., Figs. 2 to 5, and No. III., Figs. 5 to 8). If three optical lanterns are arranged to form three overlapping discs on the screen, and in one there is a red glass, in the second a green glass, and in the third a blue glass, it will be found that where the red and green overlap yellow is obtained, where the red and blue overlap then violet is produced, and where the blue and green overlap a greenish-blue is the result, while in the centre will appear a triangular white space where all three of the colours overlap.

To obtain the best results, care is necessary in selecting the red, blue and green glasses so that they may be of the

PLATE VI.



(THEORY OF COLOUR). Colour Contrasts. *To face p.* 80.

right hue, and probably many will have to be rejected before the right ones are obtained.

We now see the fundamental difference between the old and the new theories. In the old theory, based upon the admixture of pigments, the admixture of the three primary colours gives rise to the production of a tertiary colour; while in the newer theory white is the result, which is not only true in theory but in fact, for, as already explained, white light is composed of all the colours of the spectrum, and these are mutually complementary.

If, instead of adding coloured lights together to form white light, we take away one of the primary colours from white light, there will be left, according to the Young-Helmholtz theory, a combination of the other two primaries: thus, if we take away blue there will be left yellow, which is produced by the combination of the other primaries red and green; if the red be next taken away we shall have green left; and if this be taken away we shall have no light at all; in other words, all the rays of light are removed and blackness results. Now it having been shown that the colour of bodies is due to their possessing an absorptive action on the light which passes into them, a black body is black because it absorbs all the light which enters into it.

According to the Young-Helmholtz theory the colour effects obtained by mixing pigments, dyes or colouring matters together are due to the absorptive action of the colouring matters upon the light which falls upon them. This absorptive action results also in a reduction in the intensity of the light, therefore the colour which is produced by the mixture of two or three other colours is weaker as regards its light intensity and therefore appears duller or darker; in the end, by total absorption of all the light, black results. How soon this occurs depends entirely upon the colouring matters which are used; in some cases—as, for instance, when

the dyer uses Azorubine and Acid Green—two will suffice, in other cases three or more may be required.

If the colouring matters are so mixed together, that while there is considerable reduction in the intensity of the light, the colours being such as would form an orange—that is, red and yellow predominate—then brown will result; if, on the other hand, green is predominant the resulting colour will have an olive hue, while plum shades will result when the red and blue predominate.

In a similar manner we may account for the production of all the secondary and tertiary hues produced by the admixture of pigments and colouring matters together. If there is an absorption of light which tends to produce the same effect as adding black, then the predominant colours show themselves somewhat in the manner indicated above.

Maxwell's Theory.—This closely resembles that of Young and Helmholtz, differing from it only as to the hue of the primary colours. Maxwell regards scarlet, green and a violet tone of blue like ultramarine as the primary colours, the wave lengths corresponding to the true primaries being in millionths of an inch, for the scarlet 2328 between lines B and C, for the green 1914 near line E, and for the blue 1717 near line G. As regards the secondary colours obtained on mixing the primaries together and the relationship of primary and complementary colours, Maxwell agrees in all essential particulars with Helmholtz. In 1861 Maxwell demonstrated the correctness of this theory in lectures at the Royal Institution.

A solution of sulphocyanide of iron matches well the primary red, one of chloride of copper the primary green, and one of ammoniacal sulphate of copper the primary blue. With three lanterns, and using troughs filled with these solutions, many experiments on the mixture of the primary colours may be made.

Colour Photography.—The production of photographs in the colours of nature has occupied the attention of scientific men for a very long period, and, although it is not yet possible to produce a coloured picture at one operation on paper by photographic means alone, the results obtained with transparencies and by the aid of the three-colour process of printing are very beautiful and fully repay for the labour already spent, at the same time giving promise of further developments in the future.

In the early days of photography the attempts necessarily lacked any scientific basis, but since the theories of Young and Helmholtz and Clerk Maxwell were propounded the subject has developed on a firmer footing and much more rapidly. The phenomena underlying colour photography are therefore the same as those described in this book which renders it an interesting subject for us to study from this point of view.

Several of the early experimenters in photography appear to have produced coloured pictures on paper sensitised with silver salts, although they were not able to fix them and render them permanent. Thus in 1839 Sir John Herschel, at a meeting of the Royal Society, described the production of a coloured image of the spectrum in this way. Whether the colours were as brilliant and true in position as those of the spectrum or were simply due to iridescence we do not know, but the existence of coloured haloid salts of silver was demonstrated in 1887 by W. Carey Lea, who named them "photo-salts," these being produced from the chloride, bromide, and iodide of silver by reducing agents and also by the action of light.

The first step of any importance in colour photography was made by Professor Clerk Maxwell, who, lecturing at the Royal Institution in 1861, exhibited a number of interesting experiments on light and colours. He showed among other things three photographs which had been taken of the same coloured

object under a red, blue, and green glass respectively. On projecting these together from three optical lanterns, each photograph being illuminated by the light with which it was taken, an image was obtained which showed the colours of the original.

In 1865 Henry Cullen described how it might be possible to obtain a coloured photograph taking three negatives of the same object, one under a blue, one under a red, and one under a yellow screen, then by using these in pairs, and exposing over a film which was sensitive only to the remaining colour three positives would be obtained which when laid upon one another on a white surface would give the form and colours of the original object. Although merely theoretical at the time these ideas were later carried out. In 1867 Charles du Cros obtained a patent for a process in which three negatives were prepared, the subject being illuminated with red, yellow, and blue light in rotation. Positives were made from these negatives, then stained, and on examination in a suitable apparatus they were combined to form one multicoloured image. A year later Ducos du Hauron brought forward two processes, one of which introduced a new principle, that is the use of a screen ruled with lines of three colours, later elaborated by Joly. In 1869 Ducos du Hauron introduced another process, using screens as above, but printing upon separate transparent films tinted with the complementary colours, the three being combined. In 1881 Du Cros described still another method in which a sensitive surface was tinted with certain colours each of which was bleached when exposed to light the colour of which was complementary to it.

Mr. F. E. Ives, of Philadelphia, considerably improved upon anything which had been done before by applying the results of Clerk Maxwell scientifically, and introduced three colour screens which were adapted to give accurately the three colour

sensations as shown in Fig. 58. In this process a special camera capable of taking the three pictures at the same time is employed. The times of development have to be adjusted so as to obtain as nearly as possible equal density on all the plates. Then by examination of the three together in an instrument called the "Photochromoscope" or "Kromscop" a perfect coloured picture was obtained.

The Photochromoscope consists essentially of a box, open at both ends, with three coloured glasses or screens (red, green and blue-violet) and three pairs of small mirrors arranged within it. With such a simple device it is possible to view the monochromatic triple image of the chromogram as a single image reproducing all the colours of the object photographed; but in order to magnify the image, to improve the illumination, and in other respects to add to the efficiency and convenience of the instrument, it is constructed upon a more elaborate plan, with condensing lenses, colour screens, mirrors, objective lens, focussing eye-piece, etc.

THE KROMSKOP.

This instrument consists of a case with five pieces of coloured glass, a reflector and eye-lenses, which are so disposed as to blend the images, either single or stereoscopic, and focus them upon the retina.

The construction and operation of the Kromskop may be readily understood by reference to a diagram (Fig. 53). A, B and C are red, blue and green glasses, against which the corresponding images of the negatives are placed when the instrument is in use.

D and E are transparent reflectors of coloured glass. F represents the eye-lenses for magnifying the image. Beyond C is a reflector for illuminating the images at C, those at A and B being illuminated by direct light from above.

The operation of the Kromskop is as follows: The green

image is seen directly, in its position at C, through the transparent glasses D and E. The blue image is seen by reflection from the surface of the glass, D, and also appears to form part of the image at C. In the same way the red image is seen by reflection from the surface of the glass, E, and also appears to form part of the image at C. And finally the eye-lenses at F not only magnify but cause the eyes to blend the two images which constitute the complete stereoscopic pair, as in the ordinary stereoscope. The result is a single image, in solid relief and in the natural colours.

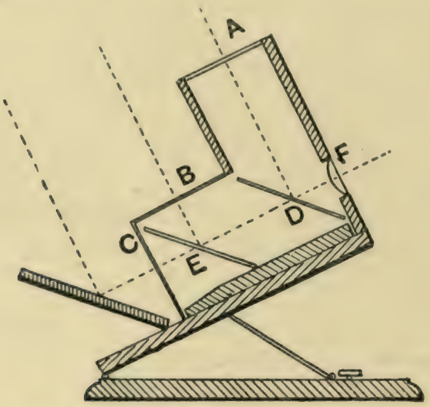


FIG. 53.

More recently a similar although simpler instrument was invented by Barnard and Gowenlock to which the name "Kromaz" was applied.

In 1895 Professor J. Joly of Dublin described his process in which only one negative is needed, this being taken through a screen ruled with extremely fine lines in red, green, and blue-violet alternately, which is placed in intimate contact with the negative. The plate used is a panchromatic one, that is, sensitive to all colours, and a yellow screen is also employed to cut down the blue and violet rays which are photographically much more active than the others. The

effect on the negative is to produce a number of fine lines corresponding to the different colours acting, and in their proper place on the negative. By viewing a positive made from the above negative through a similarly ruled screen in which appropriately coloured lines are ruled, the objects appear in their proper colours.

In the Sanger Shepherd process three negatives are taken, either at one and the same time in a special camera, or separately in an ordinary camera, through red, green, and violet filters, the times of exposure necessary to obtain equal density on the three negatives being regulated by a preliminary trial. From the negative taken through the red filter a greenish-blue print is obtained by making from it a black tone lantern plate, bleaching this in a solution of ferricyanide of potassium and then staining in a greenish-blue (or minus red) medium and fixing in hypo. The pink (or minus green) and yellow (or minus blue) films are made upon a sensitised celluloid film from the other two negatives. This film contains gelatine and bichromate of potash, so that after exposure the portions unacted upon by light can be removed by warm water. The bromide of silver is then removed from the picture by immersion in hypo. The prints now appear quite clear. They are cut up and steeped in the appropriate dyes, forming the pink and yellow images.

The pink film is now placed over the greenish-blue lantern plate and upon this is laid the yellow film, the whole being moved about until they appear in proper register, they are then bound together and the picture is complete. The transparencies thus produced can be shown with the optical lantern or in a stereoscope, the results being exceptionally good.

MM. Auguste and Louis Lumière of Lyons have introduced two methods of colour photography, the original consisting in taking three negatives through green-blue, violet and orange screens respectively. From these negatives three

prints are obtained on bichromated gelatine papers, the prints being developed in warm water and then stained by suitable dyes; that taken from the negative exposed to green light being dyed red; that from the blue-violet negative, yellow; and that from the orange negative, blue. After stripping these from their paper supports the gelatine films are superimposed and fixed in proper position upon one support.

The later Lumière process is, however, of more interest, as it introduces an ingenious method whereby only one negative is required. The negative is prepared by spreading upon glass a mixture of fine starch granules having a diameter of $\frac{1}{15000}$ to $\frac{1}{20000}$ of a millimetre, these being stained in three colours, red-orange, green and violet. The starch grains are fixed in position by a varnish and upon this is poured a panchromatic emulsion—that is one sensitive to all colours. The plate is exposed in the camera with the glass side towards the lens, so that the light passes through the coloured starch grains before reaching the film. Each starch grain thus acts as a light filter for its particular colour, and a negative is obtained covered with minute dots representing colour impressions. From this negative a positive plate is prepared which when viewed in conjunction with a similar screen to that used in taking will give a coloured image.

The diffraction grating process due to Professor R. W. Wood of Madison, U.S.A., is another ingenious method of colour photography. Three negatives are here required, made from the same picture, using screens of red, green, and blue-violet. These negatives are then exposed in rotation over a single positive plate, sensitised with bichromated gelatine, but with each negative a diffraction grating is also employed. The diffraction grating for red having 2000 lines ruled to the inch, that with green 2400, and that with violet 2700. The positive is then developed by soaking in warm water which dissolves out the unaltered gelatine. Viewed in the ordinary way, this

PLATE VII.

A.—Yellow Print.

B.—Red Print.

C.—Combination of Yellow and Red.

D.—Blue Print.

Combined Three-Colour Print.

positive shows practically nothing, but when viewed in a special apparatus and illuminated by light passed through a lens the objects in their natural colours become visible.

The Paget process of colour photography has certain features which recommend it for general use. It is simple and inexpensive, while the negative may be used for ordinary printing out as well as colour printing, at the same time any number of coloured positives can be obtained from it. The negative is taken in an ordinary camera behind a taking screen which is covered with a regular pattern of minute squares of red, blue, and green. A yellow light filter is also employed to reduce the effect of the blue and violet rays. The negative does not differ in appearance from an ordinary negative. From this negative a transparent positive is made in the ordinary way. The positive is then placed under a viewing screen, similar to the taking screen, and the two moved about into register, when the colours appear exactly as in the original subject; the two are then bound together.

An interesting development of colour photography is the three-colour process of printing. In this method the negatives are prepared as already described, using red, blue, and yellow screens respectively. It must be remembered that these screens not only allow the particular pure colour to pass through but also that portion of the same colour which is present in secondary and tertiary tints. Thus blue allows pure blue to pass and also a proportion of the green, yellow allows yellow to pass and also orange, while red allows red to pass and also a portion of the violet. From these negatives positives are prepared on zinc blocks sensitised on the surface with bichromated gelatine. These are developed in the ordinary way and after further treatment are etched with acid, the particular coloured portions standing in relief. The picture is printed with these blocks in rotation using the proper coloured inks, the result being a picture which is remarkably natural

in its appearance (see Plate VII.), and a great step in advance of the old-fashioned coloured pictures in which a separate block had to be used for every colour, simple or compound, and which therefore was limited to a very few tints, which did not blend with one another but stood out in bold relief, thus giving a very harsh and unnatural effect.

The foregoing outline of the development of colour photography, although necessarily limited in its scope, serves to show the value of the practical application of the colour theories which have been described in this book.

Hering's Theory. Hering has proposed a theory in which it is supposed that there are six primary colours, arranged in pairs, black and white, red and green, and blue and yellow, each pair being connected with corresponding sets of nerves in the eye, but this theory does not add anything to our knowledge of colour vision. The physiological aspect of the various colour theories will be discussed in the chapter on the physiology of light.

CHAPTER IV.

THE PHYSIOLOGY OF LIGHT.

THE sense organ by means of which we perceive the phenomena of light and colour is the eye, of which man has two, situated in the upper portion of the face, and each similarly situated. The eye is a globe loosely placed in a cavity known as the orbit, its movements being controlled by a number of muscles; the eye and the orbit are shown in Fig. 54. A section of the eye is given in Fig. 55, where it is seen to be a hollow ball formed of a very dense and muscular tissue, the front portion of which is transparent, while by far the largest portion is opaque. The transparent portion is known as the cornea, shown at *Cn* in the figure. The opaque portion is called the sclerotic, and is shown in the figure at *Scl.* The interior is divided into two cavities, a small anterior cavity at *Aq* next to the cornea, and a posterior cavity, *Vt*, by means of a transparent crystal structure *Cry*, the function of which is to act as a lens on the light which passes through the cornea. In front of the lens is a kind of diaphragm, *Ir*, known as the iris, in the centre of which is a circular hole, the pupil, the main use of which is to simply allow the light to pass through the central portion, which is the most useful portion of the lens. The anterior cavity, *Aq*, is filled with what is known

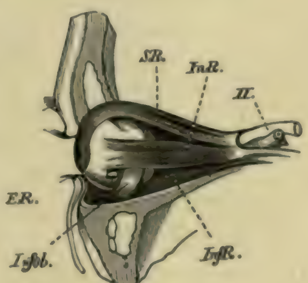


FIG. 54.

as the aqueous humour, while the posterior cavity is filled with a fluid substance known as the vitreous humour. In close contact with the sclerotic is a muscular member which, on account of its containing polygonal cells and pigmentary matter, is known as the choroid, marked *Ch* in the drawing ; this choroid coat goes all round the interior of the eye, and in front it is attached to the muscles of the lens by ciliary processes. Immediately in front of this coat is another highly important

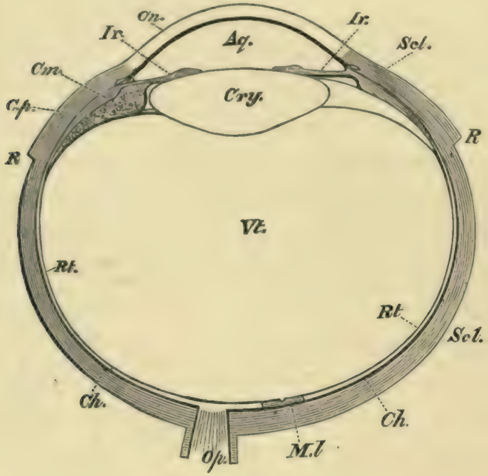


FIG. 55.

one, the retina, marked *Rt* in the drawing. This retina is a highly nervous structure, which plays an important part in the observation of light. The retina is in connection with the optic nerve and is a continuation thereof, as is shown in the drawing where *Op* represents the optic nerve.

Fig. 56 is a vertical section of the human retina as seen under the microscope. There is first of all at *i* next to the sclerotic what is known as the anterior limiting membrane, while next to this is a layer of nerve fibres which separate themselves up into the small fibres, passing through the sub-

stance of the retina. Upon this at *hH* is a layer of nerve cells; again above these is a mass of granular tissue, the granular layer as it is called, and a small layer is at *gg'*, while between these two occurs what is known as the anterior nuclear layer, a small layer; the exterior layer is at *dd'*. At *bc* is what is known as the external limiting membrane, which allows the nerve fibres to pass through to the undermost portion of the retina. This consists of a layer, *b*, of rods and cones as they are called. It is in this layer of rods or cones that the nerve sense for light is supposed to reside. The retina is uniformly distributed over the surface of the eye except at two places, one in the middle and in the line of vision, where there is a slight depression of a yellowish hue, this is known as the "yellow spot," or the macula lutea, and the blind spot, which on the under side has a radial appearance, caused by the entrance of the optic nerve, which spreads over the retina from that point as a centre.

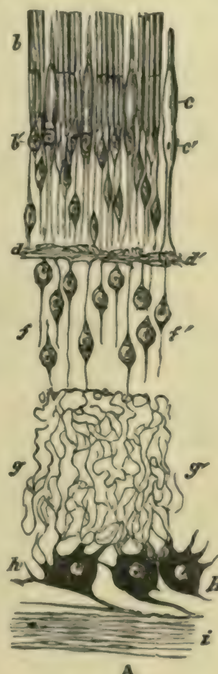


FIG. 56.

At the yellow spot the rods are absent, and the fibres fewer in number, only the cones being present, while the yellow colour is due to a small deposit of pigmentary matter.

Persistence of Vision.—When an image of an object is formed upon the retina it remains there for a perceptible period of time. This duration of the impression on the retina is the cause of many illusive phenomena being observed by the eye. Thus if a black disc be fitted to the rotatory apparatus shown in Fig. 44, and on this disc is placed a small

patch of white, the disc then being rotated, we observe, not a patch of white on black, but a grey ring which does not vary in intensity with rapidity of rotation. The tint of the grey produced depends upon the proportion between the patch of white and the amount of black at the particular distance from the centre of the disc; if the white patch be made longer then the grey will be lighter, but if the patch be shorter then it will be darker. If a disc be so arranged that one half of it is black, and the other half white, then the grey which is produced by the rotation of the disc has half the luminosity of white light. That this is so can be proved experimentally in the following manner: A prism of calcspar will produce two images of a strip of white paper; each of these images is just one half or nearly one half the luminosity of the original. Now if the grey produced by the rotation of the black and white disc be compared as regards luminosity with one of the images formed by the calcspar, they will be seen to be practically the same.

Grey may be produced by the rotation of a disc which contains alternate black and white spots. The intensity of the grey is not changed by an alteration in the speed of rotation and it is quite independent of the absolute duration of the periods of light and dark. This can be shown by the employment of the disc shown in Fig. 57, in which the disposition of the black and white portions is such as to produce variations in the proportions or duration of light and dark as the disc rotates. If this disc be rotated at a speed of twenty revolutions per second, then the periods in which these alternations of light and dark exist are, for the inner zone $\frac{1}{25}$ of a second, in the middle zone $\frac{1}{50}$ of a second, and in the outer zone $\frac{1}{10}$ of a second, the alternations of light and dark being equal. On rotating the disc it will be noticed that the grey produced in the three zones is of the same degree of brilliancy, while a quicker speed of rotation makes no difference in the results.

Many fireworks, notably the pin wheel, depend for their brilliancy and form upon this phenomenon of persistence of vision; they are produced by the rotation of a single point of light. Perhaps the simplest of such experiments is when a live spark on the end of a stick is made to revolve, when it produces a ring of light, and yet it is very evident that at any single moment there must be just a minute spot of light and not a ring at all. In such a phenomenon the rapidity of

FIG. 57.

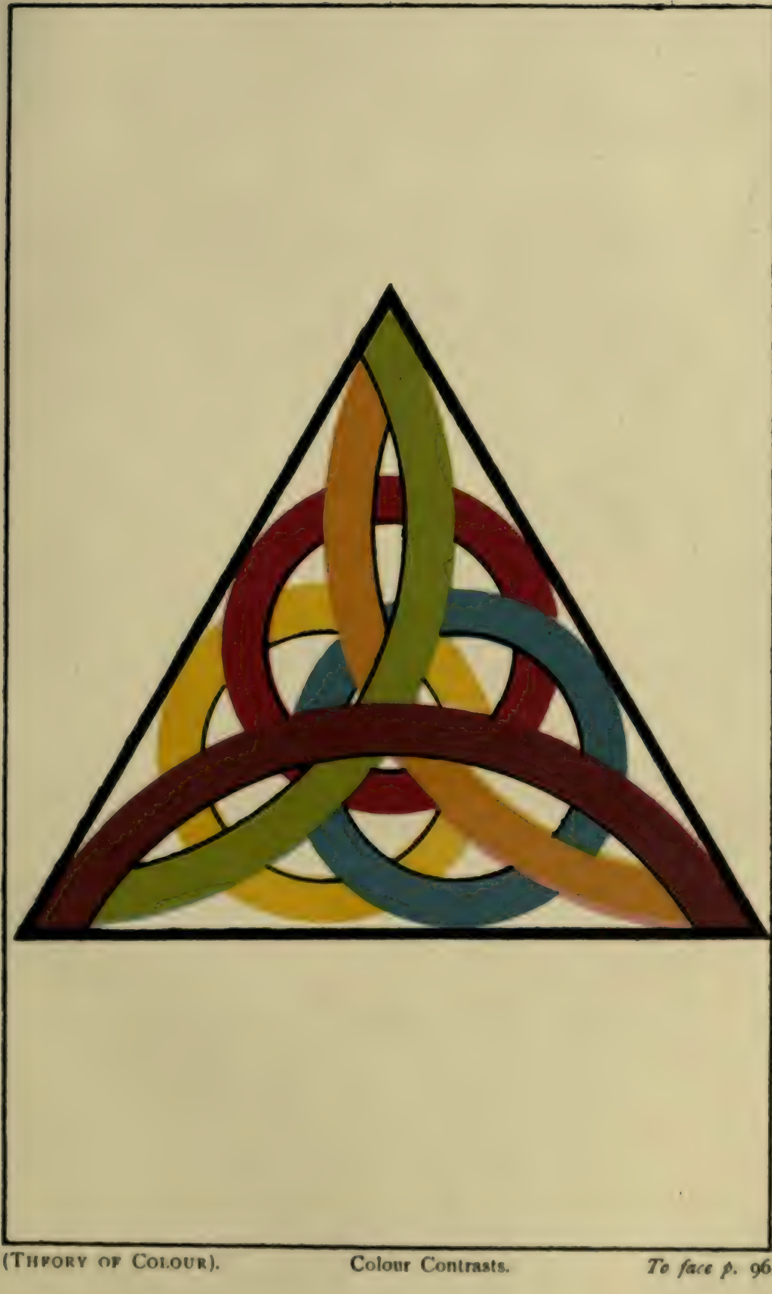
rotation is of importance; the motion may be so slow as not to show the presence of a ring of light at all; there must be a certain degree of rapidity, and from observations made by D'Arcy the average rate of rotation should be one revolution in $\frac{13}{100}$ of a second, but the rapidity varies with different bodies. Thus in some cases it is necessary to have a revolution once in $\frac{1}{48}$ of a second. This is the measure of the duration of an impression produced on the retina with almost full intensity, but there is reason for thinking that the duration is often less than this, then it decreases and fades away

entirely. Speaking generally the time of duration may be taken as $\frac{1}{8}$ of a second. The spokes in a revolving wheel are separately invisible from the same cause, the position they occupy taking the form of a nebulous disc.

This persistence of vision gives rise to various colour phenomena of a rather uncertain character, some of which are fairly familiar to many persons. If, for instance, a piece of red paper is hung against a white wall and observed fixedly for a few minutes, and then the eyes riveted upon another portion of the white wall, a faint green image resembling that of the red paper is observable. If a piece of yellow paper be substituted the after-image will have a bluish tint. The first impression, of the red or yellow paper in the above experiments, produced on the retina is called the positive image; while the spectral image, which is of a fainter character, is the negative image or after-image. Another method of carrying out this experiment is to take a sheet of grey paper, place it on a piece of green paper, and look at the latter attentively for several seconds; then suddenly remove the green paper, when its place is taken by a rose-red image, which, however, disappears very shortly. If in place of the green paper, red is used, then the image will have a greenish-blue colour. In the same way blue gives rise to a yellow image, violet to greenish-yellow, orange to a blue, the colour of the image being in all cases the complementary of the original colour.

We can explain these colour phenomena according to the theory of Young and Helmholtz in the following manner: In the eye there are three sets of nerve fibres, one set sensitive to green light, another sensitive to red, and a third sensitive to violet or blue light; the grey paper has an equal influence on all the three sets of nerves. When we look at the green paper the nerves sensitive to green become fatigued and rendered inert; on the other hand, the nerves sensative to red and violet

PLATE VIII.



(THEORY OF COLOUR). Colour Contrasts. *To face p.* 96.

are not much affected. When the green paper is taken away then grey light is presented to these fatigued nerves, which only faintly respond, while on the other hand the nerves sensitive to red and violet respond considerably, between them a sensation of a mixture of red and violet, that of a rose-red image, is obtained. The nerves sensitive to green being fatigued affects this image so as to make it appear fainter.

Again, take the effect which is produced when a piece of green paper placed on a yellow ground is suddenly removed, and we have an orange-coloured image of the green paper produced. This may be accounted for in this way: The green nerves are fatigued while the red and the violet nerves are still fresh; when the green paper is removed, yellow light is only presented to the eye, and yellow being produced by a combination of red and green, it tends to act upon the red and the green nerves equally, but the green nerves being already fatigued, do not readily respond, and so the red nerves overpower the much weaker green nerves, the union of the red sensation and the yellow sensation on the paper gives rise to the effect of orange; in this particular instance the violet rays are but little affected.

If a small piece of black paper be placed upon a sheet of red paper and the patch of black observed intently for some time, on suddenly removing the latter, there will be observed a luminous spot of red, much more intense than that of the red ground. In a similar way, if a green ground be substituted for the red the after-image of the central spot is much more intensely green. We may explain these effects by considering that where the black spot is focussed upon the retina the nerves in that part are not affected to any appreciable extent —at all events the three sets of colour nerves would be equally affected; but the red or green nerves, as the case may be, on the other portions of the retina being more or less fatigued, this fatigue causes a reduction in the intensity of the sensation they

produce; while on the other hand, where the black spot has been, the red or green nerves are quite fresh, and readily produce the appearance of a more intense image than the rest of the ground.

This experiment also serves to illustrate another phenomenon which is very frequently met with, and that is, when a coloured object has been looked at for some time, or when a number of objects of the same general colour, such as reds or greens, have been under observation for a long period, the eye loses it sensitiveness, the colours of the objects becoming dull, and losing their brilliancy. This may be explained by the fact that the coloured light from any coloured object not being quite pure, while in the main it acts upon one set of nerves, the other two sets are also brought into action to some extent; thus red light excites to a considerable degree the red nerves—it also excites slightly the green nerves and the violet nerves. The red nerves soon begin to be fatigued and lose much of their power, while the other sets of nerves are but slightly affected, therefore gradually the sensations of green and violet are added on to the red, and so the colour becomes more greyish or of a dull tone. In the same way, while green excites most powerfully the green nerves, yet the red and the violet are also slightly affected; the green soon loses its power, and the red and the violet begin to exert their influence and a greyish-green is the result.

Clerk Maxwell having investigated the sensitiveness of the colour-nerves of the eye, has shown that, while the red colour nerves are most excited by red rays, they are also excited in a much lesser degree by other colours; in the same way the green colour-nerves are most sensitive to green, but are also sensitive to other colours; and similarly the blue colour-nerves are most sensitive to blue, still other colours excited them to a lesser degree. Fig. 58 shows the curves of sensibility which Maxwell has drawn for each of the three sets of colour-nerves.

Dyers, calico printers and cloth examiners, who have to examine and pass coloured goods, find their judgment affected when they have been looking over a number of pieces of the same colour, the later pieces not appearing so bright or of the

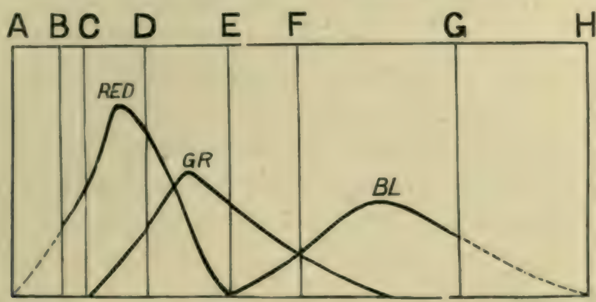


FIG. 58.

same tone as the earlier pieces. To overcome this defect it is necessary to pass from one range of coloured goods to another range —as, for instance, from reds to greens or blues.

This peculiar phenomenon is rendered more distinct if in place of the patch of black on a coloured ground we employ a

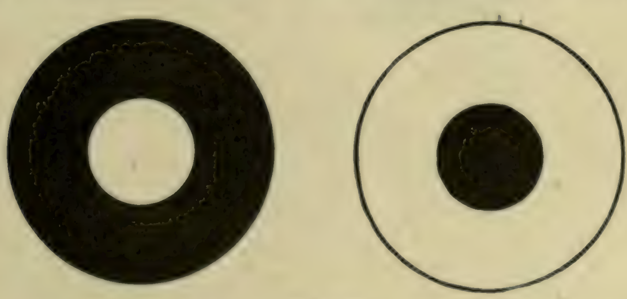


FIG. 59.

patch of a colour complementary to that of the ground—as, for instance, a patch of green on a red ground, or a patch of red on a green ground. When the patches are removed the subsequent after-images are much more intense, because they are surrounded by a colour having an entirely opposite effect.

Many examples of such colour phenomena might be given, but these are sufficient to illustrate what are commonly known as "successive contrast"; when we look upon two different colours in succession to one another. Persons who have, in the course of their business, to examine tints of coloured bodies, find this phenomenon of successive contrast to have a material influence upon the degree of perception of colour shades and tints.

The eye is not a perfect optical instrument; thus it is subject to the phenomenon known as irradiation, and also to errors from imperfect judgment as to size, direction and relative

FIG. 60.

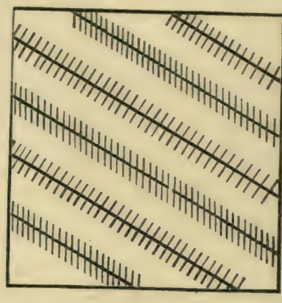


FIG. 61.

distances or direction of objects; thus in Fig. 59 we have a black spot on a white ground, and a white spot on a black ground—the two spots are identical in size, but according to the eye the white spot appears to be larger than the black spot. In Fig. 60 we have another example of this, where a square is divided into four equal squares, two white and two black; on looking at these from a distance the white squares appear to be larger than the black squares, and further that they are joined together by a short strip of white, while, as a matter of fact, they touch each other at the points. Fig. 61, which is commonly known as Zollner's lines, illustrates further that the eye is but imperfectly capable of judging correctly.

The long diagonal lines, although parallel, do not appear to be so; their inclination appears to differ. This effect is caused by the short lines which cross them—without these crossed lines the long lines would appear to be what they really are, *i.e.* parallel. Then the judgment as to the actual length of a line is much influenced by the relationship of other lines; thus in Fig. 62 the two lines A and B are of the same length, although B appears to be much longer than A. Another instance of error of judgment as to size is in observing a row of the letter S or a row of the figure 8 (see Fig. 63). Actually, the bottom halves of these figures are a trifle larger than the top halves, but to the majority of persons the top halves appear to be the same size as the bottom halves.

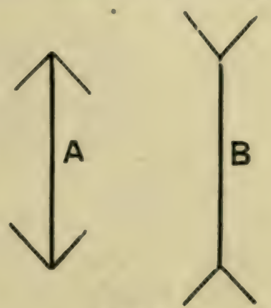


FIG. 62.

We have seen above that, by bringing about the fatigue of certain sets of nerves, we can produce an image of an object of a different colour to that originally presented. These colours are sometimes known as subjective colours, and we can produce them in various ways. For instance, if a disc

S S S S S S S S S S

8 8 8 8 8 8 8 8 8 8

FIG. 63.

of card is painted in alternate black and white sectors (or black painted upon a white ground), and placed upon the rotating machine—on rotating, the resulting disc will, after a short time, acquire a certain colour according to the speed of rotation; thus a slow rate gives rise to the production of a green hue, while an increase in the rate of revolution changes it to a rose colour. Rood describes a method of observing these subjective colours by viewing the sky through a revolving

disc with sectors; with a slow rate of revolution the sky appeared of a red tint, with a higher rate of revolution a bluish-green tint was obtained in the centre, the outer portion being purple. The passage of a current or shock of electricity through the eye gives rise to the production of subjective colours, which vary with different persons; while persons who have partaken of santonine see white objects in various colours, the violet end of the spectrum being invisible to them.

Colour Blindness.—Many persons are deficient in colour sensations. This is independent of the fact that much confusion about colours results from the very defective nomenclature which prevails. The defect referred to applies to an actual want of perception of certain colours; for instance, a person may be unable to distinguish between a red and a green. This was the case with the eminent chemist John Dalton, to whom red of the most staring hue had the same appearance as a quiet greyish-green. Such persons are said to be colour blind, and the phenomenon itself is known as colour blindness, sometimes as Daltonism. To such persons the spectrum is restricted, they see in it only two or three colours. If they are deficient, as is usually the case, in the perception of the red rays, they only perceive two well-marked divisions, which they call yellow and blue, the yellow including all the spectrum lying between the extreme red and yellowish-green, while the blue includes the rest of the spectrum. Often there is in the middle portion of the spectrum a neutral zone in which no colour is perceptible; in the majority of cases this neutral zone is the position of neutral green to the normal eye.

Maxwell, who investigated the phenomena of colour blindness with the aid of his discs, showed that any colour observed by those afflicted with this malady could be matched with the aid of two colours along with black and white, which proves that colour-blind people perceive only two of the three funda-

mental colours which are visible to the normal eye. Helmholtz has also investigated colour blindness, and arrived at the same results as Maxwell. The most common form of colour blindness is that one alluded to above, where the colour sensation representing red is deficient. In this case, red objects appear to be yellow, and it is not possible to distinguish between red and green. Another common form is where the eye is insensitive to the yellow—to such a person red and violet are easily distinguishable, but green and violet are confused together, as are also blue and red. Yellow has the same effect as, and is indistinguishable from, a bright red; one portion of the spectrum is a neutral zone and appears of a grey tint. Again, although still more rarely, we meet with persons who are colour blind to violet.

Of course there are degrees of colour blindness, as with other defects. In some persons the defect occurs only to a limited extent; they may be able to distinguish the red from the green, but only with difficulty, the difference not being so marked as with a normal-eyed person, while there are other cases where we get the extreme kind of defect, in which the person utterly fails to distinguish between various colours. Persons who are colour blind have, of course, considerable difficulty in matching colours—in fact, it is impossible for them to do this correctly. One method of testing for colour blindness is to place before the suspected person samples of dyed cotton of various hues, and ask him to select those of the same kind; if he mixes reds with greens and reds with yellows, it is evident that he must be deficient in colour sense. It may be remarked, in passing, that it is not sufficient to ask a person to name the colour of a coloured object, and judge of the efficiency of his colour vision thereby, for a person may, although not actually colour blind, give wrong names to the colours; he must be asked to match one colour by means of another.

Persons who are colour blind often confuse a colour that is a mixture of red and violet with a colour mixture of red and green; hence colour blindness and the character of the defect may often be ascertained by placing before the colour-blind persons objects coloured with mixtures of red and green; red and violet, and of green and violet, and asking them to match them by the aid of similar colours. A person colour blind to red will match a mixture of green and violet with red, while he would be unable to match a mixture of red and green, for to him this would give the sensation of white or grey. A person colour blind to green will match a mixture of red and violet with green, while a green or red also would show more or less white to him. The degree of perception of colour varies also with the same person at different periods of his life. This has often been noticed in the case of artists. The colouring of the great artist J. M. W. Turner changed considerably between his early pictures and his later ones, this change being usually ascribed to an alteration in the colour perceptive faculties of the artist.

A normal-eyed person may actually render himself for a brief space colour blind, by looking intently for some time at a red or green surface, or looking through spectacles made of coloured glass. Having thus fatigued his eye to one of the fundamental coloured rays, he will be unable to distinguish the colours of objects properly. Another plan which may be followed is to heat some soda in a Bunsen burner, when a yellow light will be obtained, sufficient to illuminate very well the whole of the objects in a room, although it is impossible to distinguish colours, red or green objects appearing to be quite black. Such facts as are thereby obtained serve to show how much colour adds to the beauty of objects.

CHAPTER V.

CONTRAST.

If we look at two coloured objects placed side by side it will be noticed that the sensation of colour or tone which each produces in our eyes is modified by the adjacent colour. This phenomenon was developed and expounded by Chevreul, who first described the laws by which it is regulated, and by him it was named contrast.

Contrast generally shows itself simultaneously in the observation of two or more colours side by side or close together. There is another form of contrast of colours, and that is, that when, after looking at one colour, we look at a second colour, in the latter case the sensation is more or less of a subjective character, while in the former case the sensation is of a much more tangible character; we may therefore distinguish, as Chevreul distinguished, between two kinds of contrast known as :—

(1) Simultaneous contrast.

(2) Successive contrast.

Simultaneous contrast is that form where we see two or more colour effects at the same time, and as the phenomenon observable has a most important bearing on the practical applications of colour, it will be of importance to study the matter in detail. We may get two forms of simultaneous contrast :—

(1) Contrast of tone.

(2) Contrast of colours.

By contrast of tone is meant the effect which is obtained when we look at or observe several tones or shades of the same colour. In Fig. 9, Plate III., we have a rectangular space divided into six equal divisions, which are filled with six different tones, from light to dark of the same grey colour. The experimenter may imitate this very easily by taking a piece of Bristol cardboard, outlining with a pencil a rectangular space and dividing this into six spaces; then having mixed a light wash of sepia or Indian ink, brush it evenly over the whole of the six divisions. This wash the experimenter allows to dry. He then covers up the first of the divisions on the left hand and applies another wash over the remaining five; this second wash is also allowed to dry. The two divisions on the left hand are now covered up and a wash applied to the remaining four divisions, and this process is repeated until finally the last division has received its wash, care being taken that each wash shall be laid on as evenly and uniformly as possible, and to facilitate this uniform washing it is recommended to cover up the left hand divisions as each successive wash is applied. Now it will be observed, on looking at this tinted rectangle, that each division does not appear of a uniform colour, but each has a fluted or hollow appearance, although really the whole of the surface of each division is perfectly uniform in tint. This shows us that, whatever may be the reason, our eyes do not always see tints and shades exactly as they are; and further, that the appearance of these tints and shades has a material influence in judging the form of the object observed.

We may get some idea of the cause of the fluted appearance represented by the six strips shown in Fig. 9, Plate III., by making another experiment which is shown in Fig. 1, Plate IV. Here are shown four strips of grey paper placed as shown in the figure; A and A^1 are of a pale tint, B and B^1 darker. Now if these are looked at for a short time it will be

noticed that a portion of A^1 which is next to B^1 appears to be paler in tint than A, while that portion of B^1 which is next to A^1 has a darker appearance than B; it is evident, therefore, that if a pale object is placed next to a dark object it appears to be paler than it really is, and similarly a dark object next

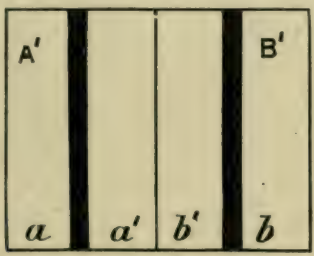


FIG. 64.

to a light object has a darker appearance than it actually is. If now the middle portions of A^1 and B^1 are covered over as shown in Fig. 64, leaving two strips of each visible, it will be observed that the adjacent strips a^1 and b^1 have a stronger contrast of tone than the strips a and b which are removed

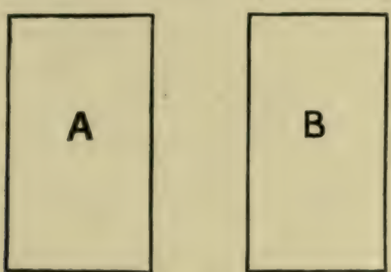


FIG. 65.

from one another. This shows us that our judgment is modified by the degree of contiguity of the contrasting objects. If we take the two strips A and B of Fig. 1, Plate IV., and place them at a short distance apart, as shown in Fig. 65, it will now be seen that the contrast between A and B of this

last figure is by no means so great as between A^1 and B^1 of Fig. 1, Plate IV.

This contrast of tone is observable with all colours when we look at different tints at the same time. The reader is advised to experiment on this phenomenon by using strips of coloured papers, light and dark shades of the various colours, and placing them in various positions, as indicated in the drawings.

Contrast of Colour.—Contrasts of colour are of a much more complex character than are contrasts of tone, and are modified according to the relative brilliancy of the colours which are contrasted, they are also often open to modifications of a subjective character, and then may present contrast of tone, while again, in dealing with contrast of tone, we have to deal with simultaneous contrast. In regard to the contrast of colour we may have also to consider successive contrasts in addition to simultaneous contrasts.

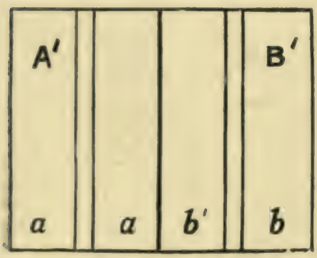


FIG. 66.

If, in carrying out the experiment which is illustrated in Fig. 1, Plate IV., we use two different colours as shown in Fig. 2, Plate IV., we make A and A^1 all red and B and B^1 all yellow, it will be seen that the appearance of A^1 and B^1 to the eye is not the same as A and B. Now it will be observed that A^1 will appear to have a more violet tone than A, and that B will have a greener tint than B^1. It is evident, therefore, that the relative positions of the two coloured spaces A^1 and B^1 have brought about a modifying influence upon the appearance of the coloured strips as represented to the eye. It may be also shown by arranging the strips A^1 and B^1 as illustrated in Fig. 66, that the contrast or modifying influence of one colour upon the other is greater if they are close together than when they

are farther apart. By carrying out a number of experiments with different coloured spaces, which can be conveniently done by means of pieces of coloured papers or dyed cloths, neither of which should have any lustre, the contrasting influence of one colour upon another may be observed.

The following table shows the influence which one colour exerts upon another when subjected to this simultaneous contrast, taken chiefly from Rood:—

	Colour pairs	Modification by contrast.
No. 1.	Red	Inclines to violet.
	Orange	,, ,, yellow.
,, 2.	Red	,, ,, violet.
	Yellow	,, ,, greenish-yellow
,, 3.	Red	Becomes more brilliant.
	Green	,, ,, ,,
,, 4.	Red	Inclines to orange.
	Blue	,, ,, green.
,, 5.	Red	,, ,, yellow.
	Cyan blue	,, ,, blue-green.
,, 6.	Red	,, ,, orange.
	Violet	,, ,, blue.
,, 7.	Orange	,, ,, red-orange.
	Yellow	,, ,, greenish-yellow.
,, 8.	Orange	,, ,, red-orange.
	Green	,, ,, bluish-green.
,, 9.	Orange	Becomes more brilliant.
	Cyan blue	,, ,, ,,
,, 10.	Orange	Inclines to yellow.
	Violet	,, ,, bluish.
,, 11.	Yellow	,, ,, bright orange.
	Green	,, ,, blue.
,, 12.	Yellow	,, ,, orange-yellow.
	Cyan blue	,, ,, bright blue.
,, 13.	Yellow	Becomes more brilliant.
	Bright blue	,, ,, ,,
,, 14.	Green	Inclines to yellow.
	Blue	,, ,, violet.
,, 15.	Green	,, ,, yellow-green.
	Violet	,, ,, reddish.
,, 16.	Greenish-yellow	Becomes more brilliant.
	Violet	,, ,, ,,
,, 17.	Blue	Inclines to greenish.
	Violet	,, ,, reddish.

If this list of pairs be examined and compared with a chromatic circle given in Fig. 67, particularly noticing the relative distances diametrically of the pairs, it will be observed that the effect of contrast is to throw each member of the pair farther apart. Thus with pairs that are already situated as far apart as they possibly can be, as is the case with complementary colours, the effect of contrast is to render each much more brilliant and distinct.

The effect of contrast may be studied in several ways

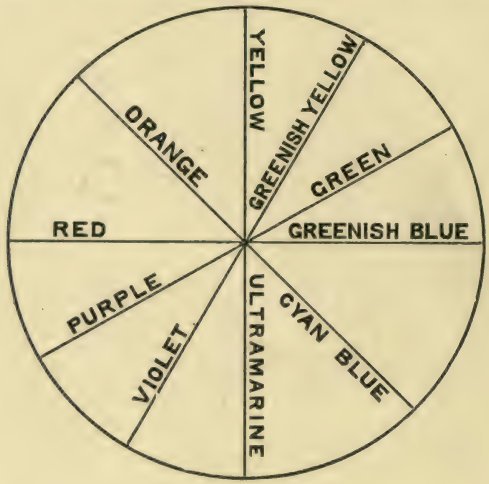


FIG. 67.

other than those already mentioned: thus in Fig. 68 it may be shown by means of a revolving disc. This revolving disc is white with four coloured sectors, which may be green or red or yellow as desired. In the middle of the sectors are placed, as shown in the figure, strips of black; on rotating the disc the coloured sectors will produce a coloured ground, while the black strips will produce a ring of grey, but it will be observed that this ring of grey becomes tinted with the colour complementary to that of the ground and contrast effects are thereby obtained.

Another form of apparatus which can be employed for this purpose is that devised by Ragona Scina, shown in Fig. 69. This consists of two pieces of board placed at right angles to one another, and covered with white cardboard or white paper. From the angle where the two boards meet there projects at an angle of 45° a piece of deeply coloured (preferably ruby) glass. Now if the eye be placed in the position shown in the drawing, it will receive light from two sources: (1) light that is reflected from the bottom of the

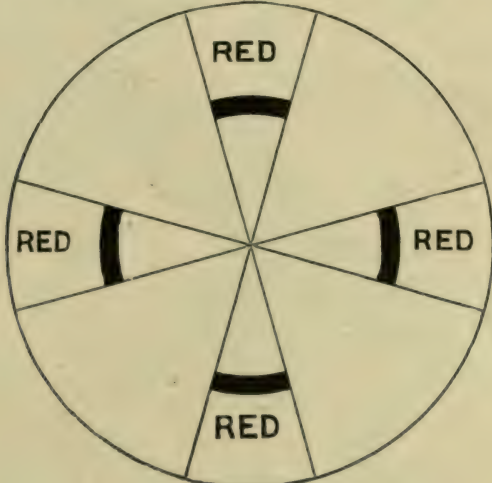


FIG. 68.

apparatus, which passes through the coloured glass, will be coloured; the eye will also receive light reflected from the side of the apparatus, which is reflected from the upper surface of the glass, and will consist mostly of white light. If a piece of black paper is attached to the right side of the apparatus, the reflection of this will be seen by the eye as if it formed a red patch, if the coloured glass be of a ruby tint, and will appear as if it were a red square at the bottom of the apparatus. A small square of black is placed at C; this will prevent any light being reflected through the glass to the eye

from that particular spot, and it should make its appearance as a black patch; but owing to the fact that the upper surface of the glass is reflecting white light, the patch shows itself as a grey; but being alongside a red patch we have the effect of contrast, and the grey patch acquires more or less a greenish tint. That this is so may be shown by removing the black square B from the right side, when the patch C will show itself in its true appearance, grey on a pale red ground. If,

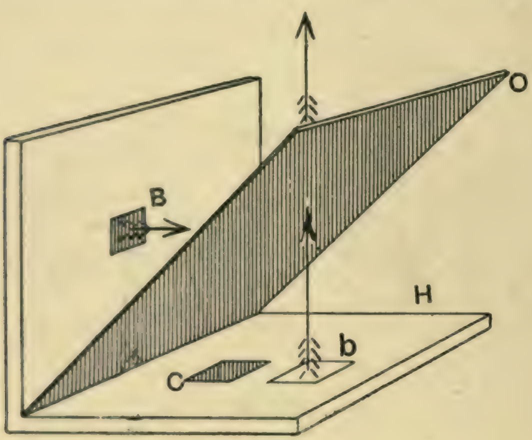


FIG. 69.

in place of employing a red glass, a blue glass were used, then the grey patch would assume an orange-grey tint.

A very interesting series of experiments in contrast may be made by producing shadows of an object with various coloured lights, white, etc., and noting the tints of the shadows thus obtained; for instance, if a rod of wood or metal is held in front of a white screen, and it is illuminated by sunlight from an aperture in a window, a grey shadow on a white ground will be produced. If now a lighted candle or gas flame be placed near, a second shadow of the rod, close to the first one, will appear; we shall now have the appearance, not of a second grey shadow, as one would expect to be

PLATE IX.

(THEORY OF COLOUR). Colour Contrasts. *To face p.* 112.

the case, but of a blue shadow on a yellow ground. The explanation of this is that the sunlight illuminates with pure white light the surface of the screen except that occupied by the shadow caused by the rod; the candle illuminates the whole of the surface with a yellow light—that is, yellow in comparison with the sunlight—except that portion covered by the second shadow of the rod, and this is illuminated by white light, which, however, by contrast with the yellow of the ground, acquires a decidedly blue tint. To obtain the best results in carrying out this experiment it is necessary to have the shadows as nearly of the same intensity as possible, which can be done by regulating the amount of sunlight admitted. If the shadows be observed through a tube the inner surface of which is blackened, then the shadow caused by the candle flame will appear to be blue, and the shadow caused by the white light will appear to be yellow, from the effects of contrast. If now the position of the tube is changed so that only the blue shadow is observed, we get still the effect of blue, although really we are looking at white light, and have no means of producing contrast effects. The candle flame may be even screened off without affecting what is visible through the tube; but if the tube be removed from the eye, the contrast effect immediately vanishes, proving that in this case the effect is due to error of judgment of the eye.

Successive Contrast of Colours.—In dealing with the phenomena of persistence of vision on page 93 we referred to colour phenomena in which, after looking intently at a coloured surface, and then transferring the gaze to a white surface, an after-image of the original surface was formed, but in a colour complementary to that originally presented to the eye. The phenomenon here referred to is of a subjective character, differing therefore from the objective sensations produced on the retina by the observation of tangible objects. The image or sensation first produced on the retina is known

as the positive image, while the after-image or sensation is known as the negative image. Phenomena such as those already alluded to have a considerable bearing on the impression which colours produce in our eyes, especially when we look at a series of colours in succession; for example, if we have been looking at a red object or a series of red objects for some time, and then turn our attention to blue objects, we find that, so far from the blue presenting its true colour to the eye, it acquires a greenish tint; a white surface viewed in the same way tends to acquire a green tone. Such subjective phenomena are not always readily perceptible, some observers' eyes being more sensitive in this direction than others. A more elaborate illustration is the following. Close one eye, say the right one, and look steadily for a short time at a sheet of red paper—in a few minutes the brilliancy of the sensation will become less; then look at a sheet of violet paper with the same eye—the violet paper will now appear to the eye to be much bluer in tone than it really is. If the right eye be opened and the sheet of violet paper observed, it will appear to be even redder in tone than it originally appeared to the left eye, the bluish-violet observed by the left eye contrasting with the violet tint observed by the right eye. Such phenomena as these are explainable as due to the fatigue of the special sets of colour nerves, which dull the sensitiveness of the eye for those particular colours. This has been explained in a previous chapter, to which the reader is referred.

This question of successive contrast of colours, brought about by first looking at one colour and then at another, has a very important bearing on the judgment of the actual colour of coloured objects. It is a fact well known to persons who have to examine dyed or printed goods of the same colour, that the eye loses its sensibility, so that after a time it does not perceive the objects in their true colours; not only so, but if the observer passes through a range of goods of one colour,

say red, quickly to a range of goods of another colour, say blue, then the latter is much influenced by the colour effect left by the former. The following table will give some idea of the modification of colour which is brought about by the successive observation of different colours:—

If the eye has first seen	and then looks at	the latter colour will appear.
Red	Orange	Yellow.
Red	Yellow	Greenish-yellow.
Red	Green	Bluish-green.
Red	Blue	Greenish-blue.
Red	Violet	Bluish-green.
Orange	Red	Reddish-violet.
Orange	Yellow	Greenish-yellow.
Orange	Green	Bluish-green.
Orange	Blue	Tinted with violet.
Orange	Violet	Bluish-violet.
Yellow	Red	Reddish-violet.
Yellow	Orange	Reddish-orange.
Yellow	Green	Bluish-green.
Yellow	Blue	Violet-blue.
Yellow	Violet	Bluish-violet.
Green	Red	Tinged with violet.
Green	Orange	Reddish-orange.
Green	Yellow	Orange-yellow.
Green	Blue	Violet-blue.
Green	Violet	Reddish-violet.
Blue	Red	Orange-red.
Blue	Orange	Yellower.
Blue	Yellow	Orange-yellow.
Blue	Green	Yellowish-green.
Blue	Violet	Reddish-violet.
Violet	Red	Orange-red.
Violet	Yellow	Slightly greenish.
Violet	Orange	Yellowish-orange.
Violet	Green	Yellowish-green.
Violet	Blue	Greenish-blue.

Some colours produced by successive contrast are much more distinct and persistent in their appearance than others: for instance, when the eye has looked at red and then at green, the change to bluish-green is brought about immediately. Again, if after having looked at violet we fix the eyes on

yellow, the contrast effect is clear and remains; while the contrast effect of blue and orange is intermediate between these two pairs. It should also be pointed out that the depth or tone of the contrasting colours has a very material influence upon the effect produced. If the eye has first looked at a reddish-orange and then proceeds to view dark blue, the latter may exhibit a greenish effect; while, on the other hand, normal blue following on normal orange would become more violet.

There is another effect of contrast to which attention may be usefully directed at this point. When we have uniform masses of two colours placed side by side as shown in Fig. 3, Plate IV., we get the effect of contrast on both these colours comprised within the rules laid down. When, however, the mass of colour is in the form of fine lines or dots, placed side by side, such as shown in Fig. 4, Plate IV., then viewed from a little distance, the eye fails to distinguish between the separate lines or points, the effect of contrast being greatly heightened; and in place of seeing the lines or points, one has the effect of a mass of colour, a combination of the colours employed. Thus when the colours are red and blue the effect produced is violet; when they are blue and yellow, green is the result. This property which colours have of mingling is taken advantage of in decorative work by printing or producing, side by side, fine lines or dots of colour, or by overprinting the lines of one colour with those of another, to produce colour effects which could not conveniently be obtained by the direct admixture of the pigments themselves.

This property of contrast is made use of very largely by designers of figured textile fabrics, who, by a judicious arrangement of the warp and weft threads, can, by using only three different coloured threads, produce a design in six tints. For example, by using red, white and blue threads in both warp and weft a figured design in dark red, pink, dark blue, light

blue, violet and white, may be produced, the dark red being formed by the crossing of red warp and weft threads, the pink by the crossing of red and white threads, the dark blue by the crossing of blue warp and weft threads, the light blue by the crossing of blue and white threads, the white by the crossing of white threads, and the violet by the crossing of red warp and blue weft threads. Other combinations of colour and effect are produced, by using other coloured yarns.

Colour Contrast in Decorative Design.—Colour contrasts have a most important bearing upon decorative design in whatever way the contrast effects may be brought about—in the production of wall papers and wall hangings, in calico printing, in weaving coloured figure cloths, the designing of carpets and floor cloths, in painting, and wherever there are brought into juxtaposition several colours which are viewed at the same time. We must therefore devote a considerable amount of attention to the influence or contrast effect produced by one colour upon another from a practical point of view. Chevreul, who was one of the first to observe the effects of the simultaneous contrast of colour, was induced to do so by being consulted in a case in which the merchants refused some printed calicoes on the ground that the colours were not equal to pattern, besides being deficient in depth, pointing out that the blacks were of various tints in the different fabrics. The printers said this could not be the case, inasmuch as all the patterns were printed with the same black and therefore should have been identical; that while some of the designs were approved of others were rejected, but they averred the colours in these were identical with those which were accepted. By cutting out pieces and comparing them independently of the designs of the goods, Chevreul showed that they were identical and of the required degree of strength, that therefore the effect of the difference in colouring was due to the influence of one colour upon the other when placed

together in the design: the black when placed against the red showed a greenish hue, while placed against a green it acquired a reddish tint; moreover, a black placed against a bright colour appeared somewhat impoverished.

Plate V. illustrates the effect of various grounds upon different colours. There are four grounds—white, black, yellowish-grey and bluish-grey; taking the various colours we see that the red on white ground appears brilliant and deep, while the ground itself has a tendency to acquire a greenish tint; orange looks bright and brilliant in tone, yellow becomes darker, is less luminous, and is not prominent, and, if anything, shows a tendency to acquire a greenish tint; deep yellow on white is much more satisfactory than pale yellow on white. The contrast between orange and white is greater than that between yellow and white, and is much more effective. Green on a white ground appears to become more intense and of a deeper tone, white evidently improving its appearance. Blue on a white ground shows a better and deeper appearance, the effect being more striking with deep blues than with pale blues. Violet on white shows a decided contrast, and is enriched considerably. It will be observed that the general effect of a white ground is to deepen and enrich the colours.

A black ground being very much deeper in tone than any colour, when employed as a groundwork its presence tends to lower the tone of the contiguous colour, while at the same time its own tone becomes modified. Now, as all black surfaces reflect a little white light, the black becomes tinted with the complementary of any colour with which it may be contiguous. There is one important fact to note, and that is, if the contiguous colour be deep in tone, blue or violet and some shades of deep red, the black tends to appear slightly weaker. Red on black has a tendency to become more luminous, and to acquire an orange tone, the black having a greenish tint. Orange and black become much more luminous, and of a

yellower tone, the black appearing to be of a bluer shade. Yellow on black is one of the greatest contrasting changes that can be produced; the yellow becomes lighter and much more luminous, while the black has an enriched appearance, due to its acquiring a bluish-violet hue. Green on black becomes more brilliant, but rather lighter in tone; on the other hand, the black acquires a rusty hue and appears impoverished, owing to its becoming tinged with the complementary colour red. Blue on black is a rather poor combination, especially when the blue is of a deep tone, the black becoming slightly rusty in tone; a light shade of blue becomes a little more luminous on a black ground. Violet on black becomes slightly deeper and richer in tone, but, on the other hand, the black loses some of its intensity and acquires a rusty hue.

Colours on grey will vary considerably according to the tone of the ground, for the name grey is a vague one, and is applied to various tints and shades markedly different in character; thus, in Plate V., there are also given two shades of grey ground—a yellowish-grey and a bluish-grey—and it will be observed that the effect of these two kinds of grey grounds on the various colours is different. Taking the yellowish-grey we note the following, that red becomes somewhat more intense and deeper, and acquires a bluish hue; orange becomes redder in tone; yellow becomes darker and rather less luminous, much depending upon the relative intensities of the yellow and the grey, pale grey having a tendency to reduce the luminosity of the yellow, while the deep grey increases it; green becomes somewhat deeper and bluer in tone; blue becomes much brighter in tone and is enhanced in quality, while violet becomes somewhat bluer in tone and brighter in appearance. With the bluish-grey somewhat different results will be obtained. The red becomes brighter and somewhat yellower in tone; orange is made a little more luminous and forms a very good combination; yellow is

rendered more luminous and deeper; green is rendered lighter and somewhat yellower in tone; violet is somewhat deadened in appearance; while there is little effect on the blue, which, if anything, is rendered slightly less luminous. These experiments will suffice to show that contrast has a very material influence on colours when they are employed in a decorative design. In another chapter some further consideration will be given to the subject of colour from a decorative point of view.

Theories of Contrast.—At the present time there are two theories which have been put forward to explain the phenomena of colour contrast—the psychological theory of Helmholtz and the physiological theory of Hering.

The psychological theory of Helmholtz supposes the existence in the eye of three sets of colour-nerves corresponding to the three primary colours; these have been alluded to in the last chapter. Now a colour not only excites that set of nerves which are peculiar to it, if it be a primary colour, or if it be a secondary colour the nerves corresponding to the primaries of which it is composed, but also, although to a lesser degree, the nerves of the colour complementary to it; a red colour will thus not only excite the nerves sensitive to red but also affects the nerves sensitive to the complementary colour green, although in a minor degree. Both sets of nerves transmit the sensations which have been excited in them to the brain. The latter, however, does not distinguish between the red sensation, which is the real objective colour sensation, and the green, which is a subjective sensation, but only sees, as it were, one colour, which must naturally be composed of two colour sensations, and will therefore be modified accordingly; thus a red will look somewhat yellower than it really is, for red and green colours give rise to yellow. In the same way green will appear rather more bluish and a blue more greenish than it really is. Yellow will appear brighter, because it brings into play all the colour nerves, and therefore excites a sensa-

tion of white light in the brain, which makes the colour apparently brighter than it otherwise would have been. When we see two colours side by side, as in Fig. 2, Plate IV., the three sets of colour nerves are excited at the same time, we therefore do not see either colour as it really appears, but in a modified manner; hence we get what are called contrast effects, which have already been described.

The physiological theory, to which Hering has given his support, supposes the existence in the retina of the eye or in the retina-cerebral substance, of a material which is called "vision stuff" ("Seh-Stoff"), and that by the aid of this material the various colour effects are brought about by chemical changes; for instance, the red changes the vision stuff in one direction, green in another, and so on. These changes are considered to be of two classes, one the assimilative or anabolic, which is induced by black, blue and green colours; while in the second the changes are dissimilative or catabolic, and are produced by white, yellow and red colours, and further, these changes may extend outside the area directly influenced by the colour cause. One experiment on which Hering relies as support for this theory can be made as follows: On a large sheet of paper place side by side a large piece of black and a large piece of white paper, the division between the two patches being vertical. Fixed in the centre and touching the vertical division attach two V-shaped pieces of grey paper with apices touching one another, one of the V's being on the black, the other on the white. Look intently at the two V's for a short time, and then turn the eye to a uniform white surface, upon which will be seen after-images of the black and white papers, and of the two grey V's; the after-image of the black and white papers will soon disappear, while that of the V on the black ground appears to be darker than that of the V on the white ground. In explanation of this

phenomenon, Hering considers that it must be due to a material change brought about by the V's in a portion of the retina-cerebral portion of the eye. This chemical theory seems, however, to postulate the presence of a substance not hitherto found in the eye, which must be exceedingly sensitive to light reactions. On the other hand, the psychological theory of Helmholtz does not presume the presence of anything other than what is known to be present in the retina, or assume any changes in the nervous system of the eye which are at all problematical.

CHAPTER VI.

COLOUR IN DECORATION AND DESIGN.

Colour plays a very important part in the decoration and design of houses and public buildings, in the ornaments with which we surround ourselves, and the materials employed in our clothing.

The simplest colour effect is produced when a single colour is alone employed, but such colour effect varies in the impression it makes upon our eyes, or, perhaps, more strictly speaking, upon our sense of colour. The sense of colour varies in different individuals—in some it is more highly developed than in others; we find therefore that a colour or combination of colours makes a different impression upon one individual than it does on another, so that it may be pleasing to one although far from harmonious to another. In this respect the sense of colour resembles the sense of sound: a combination of musical notes which grates upon the ears of one person, whose sense of musical harmony is strongly developed, would pass unnoticed by one whose sense of music is in a rudimental condition.

The impression which a colour makes upon the eye depends upon several factors—first its character, whether it be red, orange, yellow, green, blue or violet; whether it is brilliant or luminous, dull or sombre. Different colours also convey particular impressions to the mind, yellow, for instance, conveys the impression of luminosity or brightness. Blue, on the other hand, conveys the impression of coldness;

again, red conveys the impression of warmth. Hence it is that artists, when they wish to give a bright tone to their pictures, or desire to impart a brightness or warmness to the decoration of a room, employ reds or yellows; while, on the other hand, blues and violets, conveying as they do the feeling of coldness, are always used when such an impression is desired. Then, again, colours convey an impression of distance; thus red and yellow always convey an impression of nearness, while blues and greens convey an impression of distance. This is observable on Plates VI. and VIII. in which a number of combinations of colours are given, it will be noticed that the yellow and red parts appear to stand out much more prominently than the greens, blues or violets. Artists are well acquainted with this fact, and always, in painting landscapes, give a blue tone to the distant objects of the picture, while this is brought into contrast by a reddish tint which the nearer objects are made to assume.

In any scheme of decoration, when two or more colours are employed in producing the effect, we have the question of contrast entering into the case, the combinations of colours having a harmonious or inharmonious effect upon our sense of colour. When we have two colours the simplest possible case of colour contrast is presented; when, however, there are more than two colours, the colour effect becomes more complicated, and the difficulties of producing a harmonious colour scheme are increased. On Plate VI. is given a design repeated several times in different combinations of colours, which will illustrate the remarks on the harmony of contrast which are given below. The reader examining this plate is advised to cover up those portions of the plate which is not under examination, so that there is simply in view a particular colour combination that he wishes to observe, in order to avoid any effect of contrast with the other portions of the plate. The fol-

lowing tables contain a number of pairs of colour combinations, together with the effect produced on our sense of colour harmony. Before studying these tables it may be pointed out that much depends upon the tone and brilliancy of the respective colours; thus, for instance, the juxtaposition of a crimson with a yellow is a very inferior combination, but if the red inclines to a purplish tint and the yellow to a greenish, the combination becomes a fairly good one.

HARMONY OF TWO COLOUR COMBINATIONS.

Crimson and orange	Bad.
" " yellow	Inferior.
" " green	Strong but harsh.
" " blue	Good.
" " violet	Bad.
" " gold-yellow	Good.
Scarlet and yellow	Bad.
" " green	Inferior.
" " greenish-blue	Good.
" " blue	Good.
" " violet	Bad.
Orange and yellow	Poor.
" " yellow green	Fair.
" " green	Strong poor.
" " green-blue	Fair.
" " blue	Good.
" " violet	Strong-good.
Orange-yellow and crimson	Poor.
" " scarlet	Poor.
" " green	Bad.
" " blue-green	Bad.
" " green-blue	Fairly good.
" " blue	Excellent.
" " violet	Good.
Yellow and crimson	Poor.
" " green	Bad.
" " blue-green	Very bad.
" " blue	Only fair.
" " violet	Very good.
Green and blue	Very poor.
" " violet	Moderate.
" " red	Good.

From a consideration of the above tables the following rules may be laid down: First, that two colours which are closely related to one another do not form a harmonious pair —as, for instance, red and orange, and blue and green This may be observed by comparing the two star designs, Nos. 4 and 7 on Plate VI.; on the other hand, blue and red, green and violet, and also yellow and violet go well together, as may be seen on comparing the numbers 2, 3 and 5 on the same plate. Much, of course, depends upon the tone and brilliancy of the colour, as previously pointed out.

The following table gives some combinations of pigments and colours and their effect, which may be of service to artists and designers:—

Orange and ultramarine	Good and strong.
Lemon-yellow and ultramarine	Moderate.
,, ,, vermilion	Strong and hard.
Emerald green and violet	,, ,, ,,
,, ,, purple	,, ,, ,,
,, ,, red	,, ,, ,,
,, ,, orange	,, ,, ,,
,, ,, yellow	Bad.
Ultramarine and carmine	Poor.
,, ,, purple	,,
,, ,, violet	,,
Violet and carmine	,,

On looking at designs Nos. 4 and 7, in which colours are used that are related to one another, it will be noticed that they are indistinct, this indistinctness arising from the effect of simultaneous contrast on the two colours tending to blend them one into the other. By interposing between them either black or white, however, the distinctness of the colours is materially increased, as may be observed on comparing Figs. 5 and 8, in which the following colours, blue and green, and emerald-green and dark green, have been used, but are separated by black in one case and white in the other.

There is another feature of colour which enters into the

production of a harmonious colour combination, and that is what may be termed the fullness and relative proportion of the two colours which are used; thus, for instance, while a colour combination of blue and yellow, in which the blue largely predominates so far as the amount of space occupied is concerned, may be harmonious, on the other hand a combination of the same two colours, in which the yellow predominates, may have a displeasing effect—the yellow, on account of its greater luminosity, overpowering the effect of the blue. No very definite rules can be given bearing on this point, so much really depending upon the tone of the particular colours entering into the combination.

Field has endeavoured to lay down proportions between the various colours—as, for instance, he says that 3 parts of yellow are equal to 5 parts of red, or to 8 parts of blue, or that 11 parts of green formed by the combination of 8 parts of blue and 3 of yellow will equal 5 of red, or again that 13 parts of purple formed by the combination of 8 of blue and 5 of red, will balance 3 of yellow. But all such attempts at colour relations are purely arbitrary, and only true of certain particular shades or tints. No definite rules can be given by means of which the designer can with geometrical accuracy proportion the several areas of the different colours that he uses, and he must, in developing his designs, find the proper balance of colour by trial with the pigments he may be using.

When more than two colours are used in a design, the production of a harmonious contrast becomes much more difficult. The combination of crimson, yellow and blue is good; as also is one of purple, yellow and greenish-blue; or orange, green and violet. A combination of green, yellow and crimson is rather harsh; one of red, yellowish-green and violet-blue is good; while one of red, green and blue is rather poor. In colour combinations of this character, by separating them with white or black, the effect becomes much more pleasing.

Chevreul lays down the following propositions as explaining the harmonious contrast of colours.

1st Proposition.—In the harmony of contrast the complementary arrangement is superior to every other.

2nd Proposition.—The primaries red, yellow and blue, associated in pairs, will assort better together as a harmony of contrast than an arrangement formed of one of these primaries and of a binary colour, of which the primary may be regarded as one of the elements of the binary colour in juxtaposition to it.

3rd Proposition.—The assortment of red, yellow or blue with a binary colour which we may regard as containing the former, contrast the better, as the simple colour is essentially more luminous than the binary.

4th Proposition.—When two colours go badly together it is always advantageous to separate them by white.

5th Proposition.—Black never produces a bad effect when it is associated with two luminous colours. It is therefore preferable often to white, especially in an assortment where it separated the colours from each other.

6th Proposition.—Black, in association with sombre colours, such as blue and violet, and with broken tones of luminous colours, produces harmony of analogy, which in many instances may have a good effect.

7th Proposition.—Black does not associate so well with two colours, one of which is luminous, the other sombre, as when it is associated with two luminous colours.

In the first instance the association is much less agreeable in proportion as the luminous colour is more brilliant.

8th Proposition.—If grey never produces exactly a bad effect in its association with two luminous colours, in most cases its assortments are nevertheless dull, and it is inferior to black and white.

9th Proposition.—Grey, in association with sombre

PLATE X.

(THEORY OF COLOUR). Colour Contrasts. *To face p.* 128.

colours, such as blue and violet, and with broken tones of luminous colours, produces harmonies of analogy which have not the vigour of those with black; if the colours do not combine well together, it has the advantage of separating them from each other.

10th Proposition.—When grey is associated with two colours, one of which is luminous, the other sombre, it will perhaps be more advantageous than white, if this produces too strong a contrast of tone; on the other hand, it will be more advantageous than black, if that has the inconvenience of increasing too much the proportion of sombre colours.

11th Proposition.—If, when two colours combine together badly, there is in principle an advantage in separating them by white, black, or grey, it is important to the effect to take into consideration:—

(1) The height of tone of the colours, and

(2) The proportion of sombre to luminous colours, including in the first the broken brown tones of the brilliant scales, and in the luminous colours, the light tones of the blue and violet scales.

It has already been pointed out that the harmony of a combination is much increased by the luminosity and tone of the colours forming the combination. The material on which the colours are placed has also a considerable influence on the result. A combination which is fairly good on materials such as stained glass and silk, which have a lustre of their own, may be very poor on such materials as cotton or wool, or in tempera painting. But on the question of the influence of material in the harmony of colour more will be said in a subsequent section.

In regard to the use of black and white for the purpose of separating colours the following hints may be found useful: With red and yellow, black is preferable to white; with red and blue, white is to be preferred; with blue and yellow a

grey is preferable to either black or white; with yellow or orange, black agrees very well. Grey separates blue and violet better than either black or white; black should be used with orange and green, grey in connection with violet, while white can be used to separate violet and green. As to whether black, white or grey will give the best results in outlining or separating the various colours of a design, much depends upon the balance of tone of the colours used. The following rules will be found to generally cover all cases of colour combination with which the designer has to deal: (1) if the ground of an ornamental design be of a light tint or tone of colour, and the design itself be deep or intense in colour, then it will be found best to outline the design in black or in grey, or in a colour which is deeper than either the ground colour or the design colour; (2) in the case of an ornamental design, where the figure is of a lighter colour, or a less intense colour than the ground, then it will be found best to outline the figures with white or with a light shade of grey; (3) in monochrome work, where the ground and the design are in varying shades of the same colour, similar rules must be observed. If the ground be dark then the outlines should be white or grey; if the ground be light then the outlines should be of a darker shade than the general colour.

The effect of separating colours by outlines is shown in a number of the figures given on Plate VI. and in the design shown on Plate VIII., and the effect of using both black and white for the separation of the same colours is shown on both plates.

The harmony of a design or combination formed of such simple colours as red, yellow, blue, green, orange and violet is readily perceptible, but such is not the case with the more complex hues or shades of browns, olives, bronzes, etc. The differences which exist between these shades need a

well-trained eye to distinguish them, and to appreciate the harmony of any colour combinations in which they may enter. In nature often one meets with such combinations among the trunks and foliage of trees—as, for instance, the greyish-greens of lichens which grow on the trunks of the trees and contrast with the brownish tints of those members. Or we have the dark tints of the trunks and stems in contrast with the green of the leaves. Then, again, in autumn we get the russet tints which prevail among the foliage of the trees, helping to form combinations of hues which have a most harmonious appearance. Language almost fails to describe such effects, while it needs a master artist to depict them with the brush.

Following on the lines first developed by Chevreul, it is usual to divide harmonies of colour into two classes:—

(1) Harmonies of analogy, and

(2) Harmonies of contrast,

each of which can be further divided into sub-groups, as will presently be seen. It is, however, a more or less arbitrary classification, for by the term harmonies of analogy is generally meant the effect produced by the employment of various tones or shades of the same colour, or what might be termed analogous colours; while by the term harmonies of contrast is meant the effect produced by the combination of different colours, but the two kinds of harmony often pass insensibly into each other. If various shades of yellow and green are employed, they may pass so insensibly from one to the other, that we get the harmony of analogy rather than the harmony of contrast.

Chevreul gives the following classification:—

HARMONIES OF ANALOGY.

(1) Harmony of scale, which is produced when several tones of the same colour are present. These tones may be

either so graded as to run insensibly into one another, when we have the effect generally known as shading, or the difference may be rather more marked; when the interval between two contiguous tones is greater, the effects of harmony of contrast may also be observable.

(2) The harmony of tones or hues. This results when two tones or hues of about the same degree of intensity and power, but belonging to different scales or different colours, are combined together. In some such cases the effect may be displeasing rather than harmonious.

(3) The harmony of dominant colour. This effect is obtained when a landscape or picture is viewed through a lightly tinted glass, so that the colours of the objects are readily perceptible, although they are dominated by the tint of the glass, or the material through which they are observed.

HARMONIES OF CONTRAST.

(1) Harmony of contrast of scale is obtained when two tones of the same colour some distance from one another are simultaneously observed.

(2) The harmony of contrast of hues or tones is produced by the simultaneous view of tones of different heights or depths belonging to relative colours or scales.

(3) The harmony of contrast of colours of different kinds, arranged according to the law of contrast which has already been discussed.

This classification, due to Chevreul, being rather an artificial one, is somewhat forced in character; a much simpler classification, one in two kinds of colour harmony only, may be substituted. If particular notice is taken of the harmonies which prevail in nature, in paintings, and in high-class ornamental designs, it will be found that harmony can be produced in two ways: first, by employing tones or hues of the same

colour or of colours which are related to one another; and second, by the use of different colours which harmonise with one another. For shortness we may speak of this as—

(1) Harmony of succession, or seriation of tones or hues.

(2) Harmony of change of colour.

The harmonies of the first kind are often met with in nature in the petals of flowers, also more particularly in the colours of the leaves in the autumn. We may have a succession of hues passing imperceptibly one into the other, as shown in Plate IX. One sees these effects more particularly in large leaves like those of the oak, horse-chestnut, and the elm. Another example of such harmony would be when we have a succession of tones in red, orange and yellow, or of blue and green, passing insensibly from one to the other. Not only do we find such harmonies of succession or seriation in nature, but the artist finds them extremely serviceable for the production of decorative and ornamental designs for a variety of objects.

That this is so one may readily see by visiting museums such as those at South Kensington, Liverpool or Salford, and inspecting the great collections of pottery ware, textile fabrics, and ornamental work of all kinds which are exhibited there, when it will be seen that the designers of them have made full use of the kind of harmony which we have here called seriation.

The infinite gradation of shades which are met with in nature, producing many exceedingly charming effects, are due not only to changes in the general colour of the objects such as we have been already describing, but also to the play of light upon them. Artists have to take into account the peculiar action of light when portraying a large surface. Supposing, for instance, an artist wishes to depict a large sheet of white paper, or a screen of coloured drapery: if he were to paint them of a uniform white, or of a uniform colour, although he

would be representing them as they apparently are, yet we should feel that something was wrong. This is due to the fact that the white paper or the coloured drapery is not reflected to our eyes, or does not appear to us to be of a perfectly uniform tone; the play of light upon it leads to the production of minute gradations of light and shade, which influence our sense of observation. The artist taking this into consideration, accordingly portrays the white paper or the coloured drapery with some gradations of light and shade.

All the best artists are well aware of this important fact, and pay very particular attention to it. John Ruskin, in his *Elements of Drawing*, draws attention to the importance of gradation of tone, and gives this advice: "And it does not matter how small the touch of colour may be, though not larger than the smallest pin's head, if one part of it is not darker than the rest, it is a bad touch; for it is not merely because the natural fact is so that your colour should be graduated; the preciousness and pleasantness of colour depends more on this than on any other of its qualities, for graduation is to colours what curvature is to lines, both being felt to be beautiful by the pure instinct of every human mind, and both, considered as types, expressing the law of gradual change and progress in the human soul itself. What the difference is in mere beauty between a graduated colour and an ungraduated colour may be seen easily by laying an even tint of rose colour on paper and putting a rose leaf beside it. The victorious beauty of the rose as compared with other flowers depends wholly upon the delicacy and quantity of its colour-gradations, all other flowers being less rich in graduation, not having so many folds of leaf, or less tender, being patched and veined instead of flushed."

In monochrome work the succession of tones is of importance in the production of a pleasing and effective picture; when a picture in monochrome work is composed simply of

light and dark shades, the effect is extremely harsh and displeasing, the art and skill of the painter in monochrome work depends upon the careful gradation of one shade or tone into another.

Another phase of the harmony of succession or seriation may be mentioned in the spectrum, we have a series blended one into the other—we may therefore have a perfect design in which the colours are in the following order: green, blue, violet, red, orange.

A design in which the following colours are used—green, violet and orange—will be somewhat ineffective; but by introducing the intermediate colours, blue, red and yellow, the design will be made much more complete in character. If these series of colours are not sharply defined by means of outlines, they must shade one into the other, as in the case of the spectrum colours. Much of the harmony here depends upon the relation of form, and the definition of that form by means of outlines, as for instance in foliage of various tints, combined with flowers of different colours. This kind of harmony of succession of colours is very much used in artistic work, but in designing considerable care and skill must be exercised, in order to produce a perfectly harmonious result.

The subject of harmonies of change of colour has already been dealt with fully in treating upon the contrasts of colour, therefore little need be said about it here.

Harmonies of change of colour are greatly influenced by the character of the colours themselves, their relative proportions, and the employment and method of using separating lines of black, white or grey, to define the form and extent of the colours. These questions have already been referred to, and the influence of separating them discussed.

In Plates VI., IX., X., and XI. are shown designs similar to those employed in textile fabrics, wall papers, etc. They have been arranged to illustrate the principles of colour as

applied to decorative design laid down in the preceding sections. In Plate VI. we have the same design in a number of harmonies and otherwise, showing the effect of one colour on another. In Plate IX. we have a design comprising the colours orange, yellow, and yellowish-green, showing the harmony introduced by using a series of colours in succession.

In Plate X. we have a design in various tints of red, showing a harmony in tones which is rather pleasing. In Plate X. we have a design combining blue, green and violet, the result of which cannot be considered very harmonious.

ILLUMINATION AND COLOUR.

We have seen in a preceding section, page 65, that the appearance of a colour, or colours, varies according to the circumstances or conditions under which it is observed. It will be useful here if we devote a little more attention to this aspect of light and colour, and consider the modifying influence which different kinds of illumination have upon colours of objects under observation.

It must be obvious to any one that the kind and degree of luminosity—or, in other words, the quality and intensity of the light which falls upon objects—varies from time to time, and it is a matter of common observation that the appearance and tint of the colours of such objects vary in a corresponding degree. We shall subsequently see that the character of the surface of the object also has some influence on its appearance.

Objects may be observed under at least four kinds of illuminants :—

(1) Direct sunlight or diffused daylight.

(2) Artificial light.

(3) Dominant coloured light.

(4) Two lights of varying quality and intensity.

(1) It is a matter of common observation that daylight

varies much in colour, not only during each day, but at different seasons of the year. The cause of this variation in colour in the light is due to the fact that the atmosphere through which the light travels to the earth in its passage from the sun is never perfectly transparent, but is always more or less clouded in character, the degrees of cloudiness varying from that of a clear bright summer's day to that of a foggy winter. Now, when light passes through a cloudy medium, it undergoes a change which varies in degree according to the character and extent of the cloudiness. If a mass of water be observed against a black background it will appear perfectly transparent and colourless, but introduce into it a small quantity of milk or finely powdered chalk, then the water will appear of a bluish colour; the milk or the chalk forms a cloudiness in the water, which has the property of reflecting the blue rays of the spectrum to a greater extent than the rays at the red end of the spectrum, and hence the water appears of a bluish hue. It is for the same reason that the sky appears of a blue colour when observed under ordinary conditions; the atmosphere is filled with minute particles, which reflect chiefly the blue rays of the sunlight, and these blue rays make the sky appear blue. The same phenomenon may be observed in all cases where light is reflected from a medium more or less cloudy, placed against a black background. The question of the colour of a cloudy medium is dependent upon the degree of the cloudiness; should the cloudiness increase considerably and the light be observed more directly, then the reflected rays which are bluish, being reflected in all directions, while the other rays of the spectrum are transmitted in greater proportion, the blue rays tend to lose their ascendancy, therefore the light which is transmitted through a cloudy medium assumes an orange tone. It is for this reason that sunlight, when observed through a foggy atmosphere, appears of a red colour; and also the sunset hues appear of a red character, because they are transmitted

through a greater thickness of atmosphere than is the case when the sun is more directly overhead, as it is at noonday. Street lamps, for the same reason, have an orange colour on a foggy day, the particles of aqueous vapour, etc., which constitute the fog, having a sifting action upon the light from the lamps—the blue rays are reflected and scattered in all directions, while the orange and yellow rays are transmitted.

There is another feature of a cloudy medium which must also be noticed; if a ray of light be transmitted through clear water, it will pass through practically unchanged, the water not being greatly illuminated as a whole; but on placing a small quantity of milk in the water, immediately the whole tankful becomes more or less illuminated with a diffused light which is of a bluish character if viewed by reflected light, or of a yellowish or orange tone if observed by transmitted light. This is due to a scattering of the light caused by repeated reflections from one particle to another of the suspended substances which causes the cloudiness of the water and it is obvious that this scattering of light must lead to a reduction in the intensity of the light that passes through the cloudy medium. This explains why lamplight and sunlight lose so much of their intensity during time of fog.

It is necessary to point out that very much depends upon the size of the particles of the cloudy medium, as to the degree of action upon the light which falls upon it, or is transmitted through it. If they are small, they have the effect described above; but if large, they have very little selective effect. Thus it is that under certain conditions of fog and mist, the only effect is to reduce the intensity of the sunlight, but not to alter the quality of its colour; thus also it is that sometimes the light reflected from the clouds appears to be white, while at others it appears to have a bluish or pinkish hue, due to variations in the size of the particles of water of which they are composed.

(2) Illumination by artificial light. Artificial lights—gas in its various forms, oil, and the electric light—play such an important part in illumination that it is important to consider their effect upon the colour of objects, etc. It has been shown in a previous section what effect coloured light has when it falls upon other colours. Now, in the case of most of the artificial lights, the light emitted is not pure white, but is usually more or less tinted, the prevailing hue being yellow in the ordinary flame of gas, oil and the incandescent electric light; therefore the effects are the same as those which have been shown to occur when yellow light falls upon colours. It is a well-known fact that there are many colours which perceptibly change in hue when exposed to artificial light. Some of the blue and green dyes which the textile colourist uses are thus affected—blues especially are altered, so that it is often impossible to see by night whether a particular shade of dyed cloth is actually green or blue. Blacks which by daylight are bluish in tone show a dead black under gaslight. Blues tend to become greenish, and hence in designing, where the object is to be shown under artificial light, it is necessary to employ a blue of a reddish hue rather than a blue of a greenish tint. The pigment smalts changes colour in a similar manner. The amethyst, which is a pale violet by day, becomes redder at night. The sapphire, which is blue by day, exhibits a violet tint by night. Some flowers of a blue colour show a reddish tint by gaslight. All these effects are due to the deficiency of the ordinary artificial light in the blue and violet rays, therefore the objects illuminated appear to be richer in red and yellow than they really are. In many cases, to make an object appear to be perfectly white, and to counteract a slight yellow tint that it shows, it is given a bluish tint. This is more particularly shown in the bleaching of textile fabrics, where the bleached fabric has a perceptibly yellow tint. To avoid this effect it is customary to pass the fabric through a liquor containing a

small quantity of blue dye-stuff; the slight amount of bluing that is thereby given neutralises the yellow effect, and the fabric appears white in daylight. In gaslight, however, the effect of this is not appreciable, and the fabric loses its brilliant appearance, becoming more or less dull looking.

The third condition of illumination of objects is that when seen under a dominant coloured light, which has a very material effect upon them. Reference may be made to a previous section, in which the effect of one coloured light falling upon another has been discussed in some detail. One may conveniently observe these effects by looking at a landscape through various coloured glasses, if, for example, a piece of yellow glass be used it will be noticed that, while all yellow portions are intensified, but are otherwise unchanged, the red objects tend to acquire an orange cast, blue objects become a greyish-green colour, and green objects a yellowish-green colour, and so on. In many cases the effects obtained are considerable; thus, by viewing a landscape through variously tinted glasses, one may produce the changes in appearance due to various seasons. It may be pointed out, however, that the effects observed by viewing objects through a coloured glass are not the same as viewing them under coloured artificial light, because all objects illuminated by daylight reflect some white light, and this white light modifies the effect as seen through the coloured glass. On the other hand, when an object is illuminated by a dominant coloured light—such as, for instance, that which is obtained from gas or electric light enclosed in a coloured globe—no white light is reflected from them and they appear much darker.

We come now to the fourth case—that is, illumination by two lights of different qualities and intensities. This double illumination, producing striking effects, is met with very frequently in nature, especially at night, for example, in blacksmiths' forges, street illumination, and in the case of confla-

grations. It is very difficult to lay down any laws governing double illumination, so much depends upon the kind and relative degree of the two sources of light. A very simple experiment in this connexion may be carried out in the following manner:—

Place a screen formed of a sheet of white paper or white cloth in such a position that it will be illuminated by daylight and by candle-light at the same time; then place in position a rod so that a shadow is projected by each light on the paper. It will now be observed that the shadow produced by the daylight will be tinged yellow, while that from the candle will be tinged blue; these effects are, of course, produced by the different qualities of the two sources of light. The candle-light is deficient in blue rays, while the sunlight is proportionately rich in such rays. Now the shadow thrown by the candle is illuminated by the sunlight, and in consequence appears bluish, because all the surrounding parts of the screen being illuminated by both sources of light, the yellow rays preponderate, and by contrast we have a blue effect of the shadow; on the other hand, the shadow caused by the daylight is illuminated by the yellow rays of the candle-light, and in contrast to the illuminated screen appears of a yellowish tint. Very curious effects of this character are often observed in churches or chapels having stained glass windows. In such places objects are often illuminated and shadows cast by two sources of illumination—the white light from some windows, the coloured light from others; the contrasts thus produced are extremely interesting. In hilly districts, at the periods of sunset and sunrise, especially in the former case, one often gets similar peculiar effects of double illumination, inasmuch as the ground and the objects, especially of distant hills behind which the sun is either setting or rising, are often illuminated by the sun's rays, and at the same time by the illumination from the blue sky, this double illumination having results upon the surrounding objects

which are more readily observed than described. Artists, particularly, are apt to observe the contrast effects produced by double illumination, and are able to produce some very beautiful pictures by copying them as closely as possible.

All objects visible to the eye are perceptible because of the light which they reflect, as stated in previous sections of this book. The cause of colour in coloured objects has also been pointed out. In addition to the reflecting action of a substance on light, the structure of the surface has to be taken into consideration, inasmuch as it very materially affects the intensity or beauty of the colour that an object may have. This may be noticed in the different appearance that the same dye-stuff imparts to different textile fabrics; thus on silk a colour is much more brilliant than it is on wool or cotton. Again, the structure of a textile fabric has a very material influence upon the appearance of a colour. A colour is much richer when it is dyed upon a piece of silk velvet that when it is dyed upon a piece of plain silk; hence it is evident that texture of surface has a modifying influence on the appearance of the colour, and we have now to consider some of the causes which bring this about.

All objects, whether coloured or colourless, reflect some white light—even the most intense black surfaces reflecting from 3 to 4 per cent. of white light. Now, this white light which is reflected has considerable influence upon the colour which an object may have; generally its effect is to lessen its intensity. One may perhaps notice this point more particularly with metals than with other objects. Metals have considerable power, when they are bright and untarnished, of reflecting light—the greater the amount of light they reflect, the less colour they appear to have. Owing to tarnishing or other causes the power of reflecting becomes diminished, then the metals have a stronger colour. Again, a great deal depends upon the manner in which light is reflected from metallic

surfaces, and also upon the angle at which the metal is viewed. If it is viewed in such a manner that the light skims the surface of the metal—as when we look along a highly polished plate of gold—the metal may appear to be almost white; but if we look at it at a smaller angle, then the colour of the metal begins to show itself; while, if a couple of plates of metal be placed parallel to one another, then the light which is reflected from surface to surface becomes more affected, and we get a strong development of the colour of the metal—gold under such conditions acquiring a very deep orange colour. It is owing to these repeated reflections that chased or frosted gold has a much richer colour than burnished gold; and for the same reason in metallic vessels which are highly polished, the interiors appear of a much greater brilliancy than the exteriors, on account of the light suffering repeated reflections from side to side. It may be pointed out that the quality of the light is altered by this repeated reflection; certain rays are absorbed more and more, while the total amount of light reflected from the surface is less.

The influence of surface structure is also seen, in painting, the difference which exists in the appearance of the same pigments when used in water-colour drawing, or in fresco painting, or in oil-painting being very marked: in oil-paintings the surface being more transparent and homogeneous, the colours have a more intense and brilliant appearance; while in water-colour paintings the surface is more opaque, and the colours appear by no means so intense. The greater amount of white light which is reflected from a water-colour drawing than from an oil-painting brings about this reduction in the intensity of the colours.

A similar influence may be noted in regard to pottery and porcelain: colours have a brilliancy and intensity on glazed porcelain which they do not show on unglazed porcelain, this being due to the greater amount of light which penetrates into

the body of the porcelain, the light which emerges is thus more saturated with colour.

Colour plays a very important part in the decoration of textile fabrics; it is, however, materially influenced by the character of the fibre on which it is applied. The colour of textile fibres is produced partly by reflection and partly by absorption. When light falls upon the coloured fabric a small portion is reflected as white light, a somewhat larger portion as coloured light, the latter passes into the fibre, and the colouring matter on the fibre exerts an absorptive effect on this light, causing it to become coloured: it is this portion of the light that ultimately makes most impression on the eye. When one is looking at a single piece of coloured yarn, or a very thin piece of cloth, the intensity of the colour appears slight, it appears poor and weak; if, however, there are a number of threads or a number of folds of cloth, then the colour appears more intense and strong.

The various textile fibres differ from each other with regard to lustre, which depends upon their structure and power of reflecting light. Lustre has a material and beneficial influence on the appearance of dyed fabrics—a fact well known to dyers, who endeavour to enhance the beauty of the colours they produce by imparting a lustre to their goods.

Silk is the most lustrous of the textile fibres; wool ranks next, followed by China grass, cotton, linen, jute and hemp, in the order given. Silk owes its lustre to several causes: it is homogeneous in structure, is somewhat transparent, its outer surface is smooth, and is thus capable of reflecting light in definite directions; therefore more reflected light reaches the eye from silk than from wool, while the length of the silk fibre, with its smooth structure, allows the fibres to be laid more parallel to one another in throwing and weaving than is the case with any other fibre, thus increasing the reflective power of silk fabrics.

PLATE XI.

(THEORY OF COLOUR). Colour Contrasts. *To face p.* 144.

Wool comes next in its degree of lustre, but as its surface is rougher than that of silk, it does not reflect so much light, and this is more scattered than is the case with silk.

China grass may take rank next to wool in lustre. Its fibres are long and parallel in formation—a fact which goes a long way to explain its having greater lustre than cotton. The cotton fibre does not possess much lustre. This is due to its short length and its twisted character, which causes it to scatter the light falling upon it and not to reflect it in a definite direction.

Linen, jute and hemp have practically no lustre. They are fibres not homogeneous in structure, and are also somewhat rough, consequently their power of reflecting light is but small.

The effect of lustre upon the colour of dyed fabrics may be observed by dyeing the various fibres with a single dyestuff and then comparing the results. It will be observed that the colour looks more brilliant on silk than it does on wool, and more brilliant on cotton than on linen or jute. The character of the fabric has also a material influence on the appearance of the colours dyed upon it. Thus a smooth fabric never has so solid an appearance as a fabric with a raised surface. This is strikingly shown by comparing the front and back of a piece of velvet, or a piece of plain black silk, with a black velvet dyed in the same way and from the same materials. The velvet has a much more solid and rich appearance. This is due to the fact that the pile of velvet, being presented to the light, allows it to penetrate into the fabric and be more completely saturated with colour before being reflected to the eye, while the ends of the fibres forming the nap or pile reflect but little white light, and therefore the light from the substance of the pile is not interfered with. Silk velvet is richer in appearance than cotton velvet, because

of the greater direct reflective power of the fibre, cotton scattering the light more.

The loose fibrous structure of dyed woollen cloth causes it to have a greater appearance of solidity than has dyed cotton cloth, or even worsted cloth, wherein the fibres are kept closer together. Dyed cotton flannelettes, for the same reason, have a better appearance as regards depth of colour than have plain cotton cloths.

CHAPTER VII.

MEASUREMENT OF COLOUR.

THE practical colourist has often to test or examine the colouring matters he uses for their actual tone or strength, and a description of the methods in common use for this particular purpose will be useful. It may be stated, however, that we shall not concern ourselves with the methods of testing those properties of colouring matters upon which their application in the various arts of painting, dyeing, etc., depends. The consideration of such properties will be found in books relating to the special subjects, such as the author's *Manual of Painters' Colours* and Knecht and Rawson's *Manual of Dyeing*, to which we refer the reader. What we describe here are the methods for estimating the tone and strength of colouring matters of various kinds.

ABNEY'S COLOUR PATCH PROCESS.

Captain Abney some years ago described a new form of apparatus for the measurement of colour, which he called a "colour patch apparatus," this will be found described and illustrated in his book on *Colour Measurement and Mixture*. With this apparatus it is quite possible to measure the tone and value of any colouring matter.

The apparatus may be described as follows: The source of the light used is an electric arc lamp, which Captain Abney selected because it was found to be a more regular source of light than any other which was tried. The light from this

arc is allowed to fall upon the collimating lens of a spectroscope, and from thence passes through the prisms of the instrument, into a photographic camera, on the focussing screen of which it is received as a spectrum. As the reflective powers of the different colours vary they are not all brought to a focus on the same plane, therefore to allow for this the focussing screen is placed slightly oblique so as to get as near a focus for all the rays as possible. At a distance of about four feet from the camera is placed a white screen, on which the rays can be received after passing through the camera. When the focussing screen is removed the rays form a confused mass of coloured light; by interposing a lens this mass of light can be resolved into a patch of white light. If, however, a card containing a vertical slit be put in place of the focussing screen, there will be obtained a patch of coloured light upon the screen, the colour depending upon the position of the card in the camera; by moving this card to and fro there may be obtained upon the screen any portion of the spectrum which may be desired. By taking advantage of the fact that the front face of the prism reflects a portion of the light which falls upon it from the collimating lens of the spectroscope, passing this light through a lens of suitable focus, and then reflecting it from a small mirror on to the screen, it is possible to obtain two patches of white light from the same source, and therefore practically equal in value in every respect. By placing a rod in front of the screen, which can be illuminated both by the light that has passed through the spectroscope and by the light which is reflected from the mirror, we have the means of comparing the two lights in a very correct manner. If their intensities are equal, then the shadows cast by the rod will also be equal in intensity; if one be stronger than the other, then the shadows will differ also; by employing an instrument with a pair of revolving sectors, and placing these in the path of either of the beams

of light, its intensity may be reduced to any required degree.

The instrument just referred to consists of an electromotor carrying on its spindle a pair of fast and a pair of loose sectors. The latter are so contrived that during their rotation the aperture they form with the fixed sectors can be

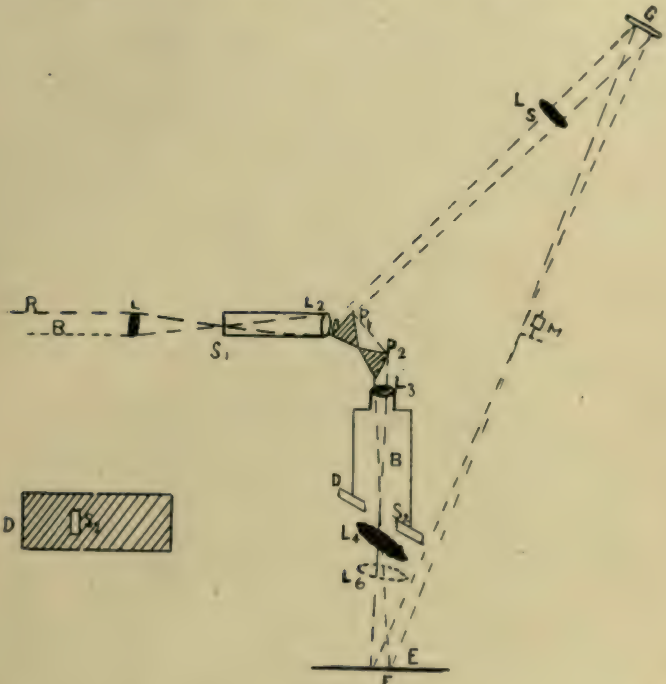


FIG. 70.

varied to any required degree, so that the amount of light which is allowed to pass through these apertures may be altered as required. The arrangement of the apparatus is shown in the diagram Fig. 70.

This apparatus can be used for the measurement of colour in the following manner: The screen is replaced by a revolving disc arrangement such as shown in Fig. 44; this revolving

arrangement carries in the centre a disc painted with the pigment which it is desired to examine; then black and white discs are so arranged that the proportion of black to white may be proportioned as required. The apparatus is arranged so that a patch of light from one portion of the spectrum falls upon the screen in such a manner that it illuminates both the centre coloured disc and the black and white sectors; by moving the slit along the spectrum the hue

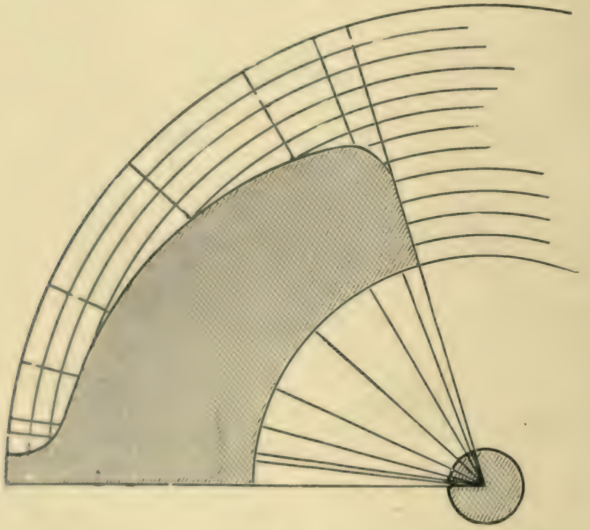


FIG. 71.

of the central disc may be matched, while its luminosity is measured by altering the proportions of the black and white sectors. In this way the exact hue of the colour may be valued, and by passing the slit along the spectrum the amount and character of the rays which are reflected by the pigment can be ascertained by laying down on a diagram the values or the position in the spectrum, and the relative luminosity of the light, and a curve can be drawn as in Figs. 20, 21, *et seq.*; further, it is possible to make a template of a

colour which, when placed in the rotating apparatus and rotated in front of the colour patch of the spectrum produced by the spectroscope on the screen, will reproduce exactly the hue of the colour. This is done by drawing a part of an arc, laying out along one of the radii the relative positions of the various rays of the spectrum, and from these points drawing concentric circles along which the relative luminosities are laid down ; by cutting out the curve so formed, a template is made which, when rotated as described, matches the colour. Such a template is shown in Fig. 71, which is reproduced from Captain Abney's book.

This method of measurement is applicable only to colouring matters in the form of pigments, or which may be spread upon the surface of a card or other medium.

THE TINTOMETER.

A very convenient apparatus, which may be applied to the measurement of a great variety of coloured substances, is the instrument invented by Mr. J. W. Lovibond of Salisbury, and named by him the tintometer. The essential part of this instrument consists of a box, rectangular in section, broad at one end and tapering to the other, in which an eyepiece is placed ; down the centre of the box is a partition dividing the instrument into two parts. If light is passed along the two tubes only one field of view is presented to the eye ; if now there is interposed in one side of the apparatus a coloured substance, the field of view of that half will be coloured, while the other half remains white. If in the second half of the apparatus another coloured substance be inserted, we have the means of comparing exactly the colours of the two products in question ; if the second coloured body is of a standard character, we have a means of comparing the first in terms of the second and also of keeping a record of the observation.

A number of coloured glasses of various hues graduated in

intensity are supplied with the instrument, these glasses being standardised and numbered. They are placed in slots provided on the one side of the apparatus while the material to be examined is placed on the other. By selecting the glasses it is possible to match any colour.

The tintometer may be used for almost any substance. Thus, suppose that the hue and depth of tint of a pigment are to be determined. The pigment may be filled into a flat box with a glass lid which is put on one side of the apparatus; a similar box filled with precipitated calcium sulphate being placed on the other; on taking an observation the colour of the pigment will be visible on the one side of the lens and white on the other. Coloured glasses are now put in one by one until the hue of the pigment is exactly matched, when the colours and the numbers are read off. For dull tones and neutral tints, smoke-grey and brown colours are provided, in addition to the pure colours.

When coloured solutions are to be examined these are placed in a narrow trough of a definite length with glass front and back, the matching of the colour following the same lines as that for pigments. Ground glasses of several degrees of opacity are provided for turbid liquids.

The tintometer can be used to measure the colour of all kinds of coloured substances and is the most practical and convenient apparatus for the purpose that has been devised. For a fuller description the reader is referred to Mr. J. W. Lovibond's *Measurement of Light and Colour Sensations.*

For the purpose of measuring tints of coloured bodies various other instruments have been invented from time to time. In Fig. 72 is shown the chromometer designed by Mr. Wilson for measuring the colour of petroleum oils, but which may be used for other colorimetric determinations with liquids. This instrument consists of two small tubes closed at each end by a screw cap carrying a stout glass disc: light

is reflected upwards through the tubes by means of a mirror, and is then, by means of prisms, refracted and brought into the eyepiece; one of the tubes is filled with the oil to be tested, and in the other, which is empty, a disc of tinted glass. On looking through the eyepiece the field of view is seen to be divided by a sharp line formed at the junction of the two images produced by the prisms, one half of the field being tinted with the colour of the oil, the other half with that of

Fig. 72.

the standard. An accurate comparison can then be made of the quality of the oil as regards colour. For the purpose of testing petroleum oil the instrument is supplied with a set of four standard glasses, representing the grades of colour of commercial petroleum oil which are recognised.

This instrument may also be employed for measuring comparative intensities, by filling the two tubes with the oils that are to be compared, and viewing them through the eyepiece.

Other similar forms of colorimeters have been devised by

Ridsdale and others, which, however, do not need detailed description here.

For examination of the comparative strengths of dyes or coloured solutions this apparatus may be used in the following manner: A solution of a known quantity of a standard colour in a measured quantity of water is made; then a solution of the colour to be tested is also made of the same strength; a measured quantity of the standard solution is placed in one of the tubes, and the same quantity of the other solution in the second tube. An observation is now made by looking down the tubes, as to whether both exhibit the same intensity of colour; if one be lighter than the other, then the quantity of the solution is added to until a new observation shows that both have exactly the same depth of tint. Then the volumes of the two liquids may be taken as measurements of the comparative strength of the two colouring matters.

When a colorimeter is not available, a comparison of two colours, such as two dye-stuffs which are soluble in water, may be made by taking a weighed quantity, say one gramme, and dissolving in 100 cc. of water. Next two tubes with flat bottoms and of the same diameter and a capacity of about 80 cc. are procured; the diameter of these need not be more than ¾ inch. Measure into each glass 30 cc. of water and 10 cc. of the dye solution, then hold the glasses in an inclined position over a white card and compare the colour of the two solutions for depth. To the strongest add water until the depth of colour in both glasses is identical; then measure the length of each column of liquid, this measurement will give the comparative value of the colouring power of the two substances.

In the case of pigments the relative colouring value of two samples may be determined in the following manner:—

By comparison with standard sample. Supposing the colouring power of a sample of vermilionette is to be deter-

mined, then 10 grammes of the sample are weighed out and mixed with 30 grammes of china clay; the mixing being thoroughly done. Ten grammes of the standard sample are mixed in the same way with 30 grammes of the same sample of china clay. The two mixtures are now spread on paper in equal thicknesses compared together for depth of colour as described above: if the two samples are equal in colouring power, the depth of colour of the two mixtures will be the same; if one is stronger than the other, then one of the mixtures will be darker than the other. Some idea of the relative strength of colouring power can be obtained by adding small and known weights of china clay to the darkest sample, until the tint of the mixtures is equal; then the samples have a colouring power proportional to the amount of china clay used. Thus, if one sample took 30 grammes of china clay and the other sample 37·5 grammes, then the relative colouring power is as 30 to 37·5; or, if the strongest sample be taken as 100, then the colouring power may be expressed in percentages thus—37·5 : 30 : : 100 : 80; the weakest colour having only 80 per cent. of the colouring power of the strongest.

Again, in making some experiments to test the comparative colouring powers of Orr's white and white lead, 5 grammes of the former were mixed with 1·46 grammes of blue, and the tint thus formed was found to be exactly matched by a mixture of 5 grammes of white lead with 0·55 gramme of blue. Hence we have :—

$$146 : 55 : : 100 = 236{\cdot}6,$$

that is, 100 parts of Orr's white is equal to 236·6 parts of white lead as regards colouring power. These proportions are, of course, by weight; as white lead is much heavier than Orr's white it naturally occupies less bulk and requires less colour to affect it.

As the toning colour for all pigments, except whites, a good sample of china clay may be used; gypsum may also be used; barytes and white lead are a little too heavy. For whites a good animal black serves as a toning colour.

When a large number of assays for colouring power have to be made, a standard tint should be prepared by taking, say, 50 grammes of the standard sample, and mixing with about twice its weight of the toning colour; this tint may be used in subsequent tests, and will save time in the preparation of a standard tint. It is important, however, that the same sample of toning colour be used to mix with the samples whose colouring power is being tested, as that used in making the standard tint.

INDEX.

D.

E.

ABERDEEN: THE UNIVERSITY PRESS.